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FEASIBILITY STUDY OF HELICOPTER-TOWED AIR CUSHION LOGISTIC VEHICLES

V. F. Neradka, et al

MAR, Incorporated

Prepared for:

Office of Naval Research

June 1975

196098

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Technical Report No. 148	2. GOVT ACCESSION NO. / 3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): FEASIBILITY STUDY OF HELICOPTER-TOWED AIR CUSHION LOGISTIC VEHICLES	5. TYPE OF REPORT & PERIOD COVERED: FINAL REPORT 31 MAR 75 — 30 JUN 75 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): V. F. Neradka, J. C. Stevens, R. L. Levin	8. CONTRACT OR GRANT NUMBER(s): N00014-73-C-0178
9. PERFORMING ORGANIZATION NAME AND ADDRESS: MAR, Incorporated 1335 Rockville Pike Rockville, MD 20852	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: Office of Naval Research Department of the Navy Arlington, Virginia 22217	12. REPORT DATE: June 1975 13. NUMBER OF PAGES: 68
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED 15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NO'

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

AIR CUSHION VEHICLES
LOGISTIC VEHICLES
LASH SYSTEMS
AMPHIBIOUS ASSAULT

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A feasibility study of a helicopter-towed air cushion logistic vehicle (ACLV) was performed. The scope of the study encompassed movement of loaded LASH system lighters on unmanned air-cushion platforms from an off-shore ship onto a sand beach in support of amphibious assault operations. Motive power is to be provided by towing with RH-53 helicopter.

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NAVAL COASTAL SYSTEMS LABORATORY
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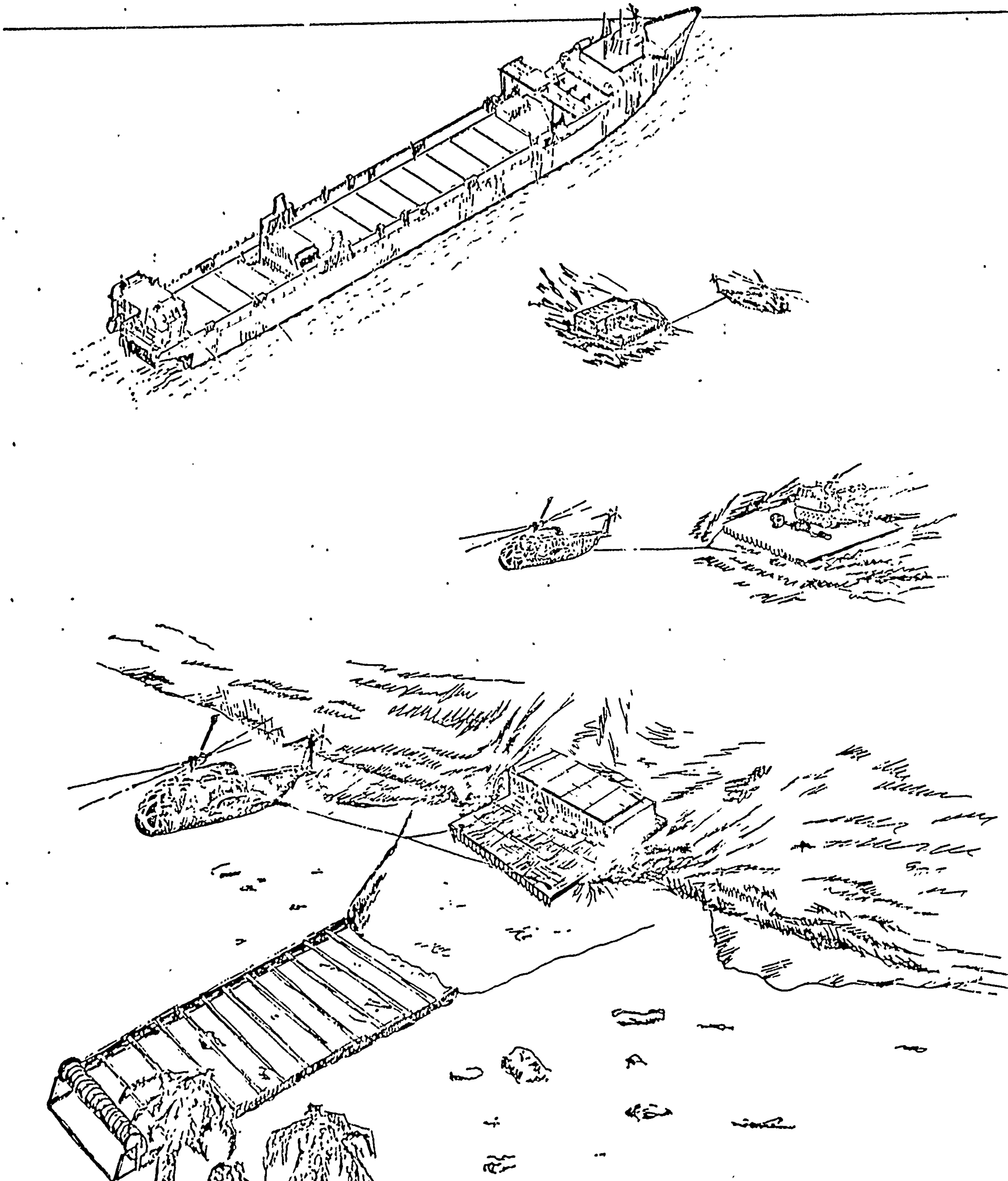

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EXECUTIVE SUMMARY

A feasibility study of helicopter-towed air cushion logistic vehicles was initiated on 31 March 1975 as a task under Office of Naval Research Contract No. N00014-73-C-0178. The scope of the study encompassed movement of loaded LASH System lighters on unmanned air-cushion platforms from an off-shore ship onto a sand beach in support of amphibious assault operations. Motive power is to be provided by towing with RH-53 helicopters.

Analyses conducted during this study indicate that the combinations of system weight, surface area, drawbar force availability and operational conditions place the feasibility of such a system within current state-of-the-art. Two basic approaches were evaluated:

- A packable system consisting of an inflatable frame with attached seal and ducting, and
- a rigid system using a flatbed platform with either a fabric or partially rigid seal.

Both approaches are technically feasible, however there are major differences in cost, durability and flexibility. The recommended ACLV system is a rigid system with partially rigid sidewall seal. This concept provides lowest costs of acquisition and ownership with the greatest operational flexibility and reliability. All the components which make up the system are commercially available as off-the-shelf items.

The feasibility study reported herein serves a dual purpose. In addition to ascertaining the fundamental feasibility of the ACLV, it also identified those areas which require further engineering prior to a full scale prototype demonstration. The uniqueness of the ACLV, requiring hands-off stability and remote operation of a very large platform over the open sea necessitates a detailed stability analysis which is best carried out through scale model testing. Structural analysis to insure reliability in operation under state 3 sea conditions must be performed. The partially rigid seal of the recommended system represents a departure from what is being used for manned craft, and this therefore requires further study. Lastly, the integration of the ACLV into the LASH ship, including handling techniques and specific ACLV details such as compressor shut-down and helicopter towing aspects are required in order *to provide a fully viable off-loading and drylanding of LASH lighters onto a sandy beach by helicopter tow.*

ACKNOWLEDGEMENTS

During the performance of the work reported herein, the following specialists in air cushion technology offered constructive criticism and advice:

Paul Klimas, USNA

John Offutt, NSRDC

John Sargent, MERDC

Joseph Sladky, USNA

Robert Wilson, NSRDC

Commercial vendors who adapted information on their products to the ACLV include:

Melvin Cohen, Avondale Shipyard

C. D. Creech, Detroit Diesel

John Niedermeyer, Buffalo Forge

Mills Spangberg, Garrett Airesearch

To each of the above the authors express their appreciation.

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Section 1

BACKGROUND

The subject study is a parallel effort of MAR, Incorporated and Goodyear Aerospace Corporation, with MAR tasked by NCSL to assess overall Air Cushion Logistics Vehicle (ACLV) system feasibility; and Goodyear tasked by NCSL to evaluate certain seal designs for feasibility and relative cost. The results of the Goodyear study are reported in Reference (1). The starting date for the MAR study was 31 March 1975, with a completion date of 30 June 1975. On 17 April 1975 the study approach paper[2] was approved by NCSL. On 5 May 1975 a review of preliminary calculations was conducted at the MAR, Incorporated offices. The conclusions reached by that review were as follows:

1. The ACLV System must provide increased cushion area in order to place cushion pressures within the realm of present state-of-the-art.

2. Reduced cushion pressure is necessary to bring drawbar requirements within the capabilities of the RH-53 helicopter.

3. Grade negotiation is negligible unless forward momentum exists upon arrival at the beach.

4. Both the packable and the flatbed systems are feasible from the seal design and fabrication point of view.

Based upon these results, additional direction was received from NCSL at that time, and work was resumed by both MAR and Goodyear toward completion of the study, the full results of which are reported herein. Appendices A thru D contain supportive data which may be found useful to fully evaluate the results of the study.

Section 2

ACLV SYSTEM PERFORMANCE

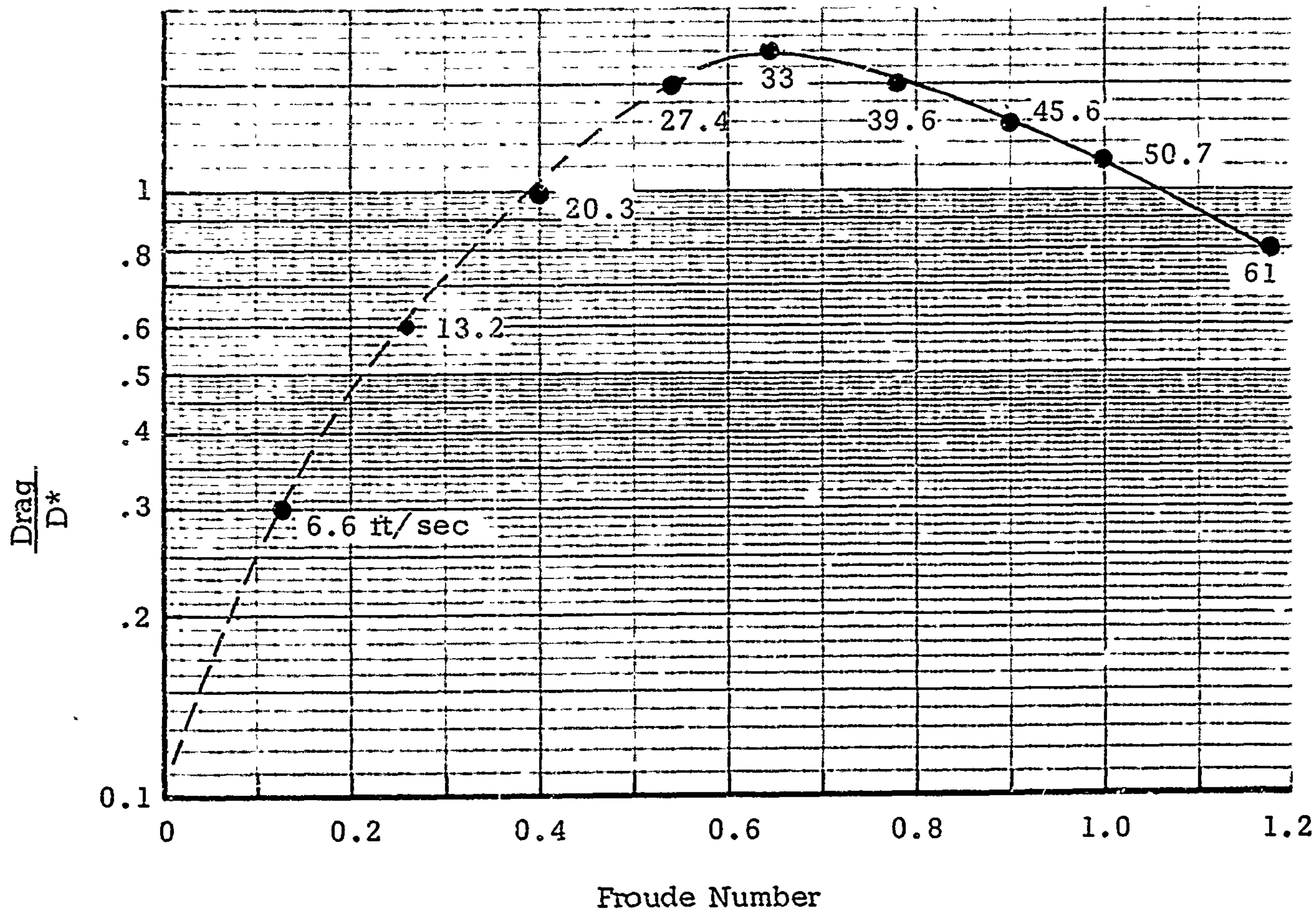
The preliminary calculations addressed feasibility from the standpoint of developing minimum requirements. Those analyses were based on a 500 short ton payload and various other system configuration baseline assumptions which were made mutually by the Navy and MAR, Incorporated. This section is a refinement and extension of those analyses based upon a reduced payload of 250 tons and the recommended system configuration to be described in Section 6 of this report.

2.1 ESTIMATES OF ACLV VELOCITY AND RANGE OF DELIVERY UP THE BEACH

The analysis of the RH-35 helicopter drawbar capacity and beach slopes indicated that the ACLV must reach the surf line at some definite speed in order to deliver the payload a prescribed distance up the beach. This, in turn, raised the question of the ACLV speed versus time (or distance). A quasi-steady state calculation has been performed in which the results of Barratt[3] are used in summation with momentum and aerodynamic drags previously calculated in a step-by step process approximating the transient acceleration of the ACLV from rest. This technique is a hand calculation following the procedure of Doctors and Sharma[4], who stated that this simple approach is somewhat conservative compared to their more elaborate computer analysis of the problem. Cross wind is assumed to be zero at this time.

2.1.1 Method of Analysis

The inapplicability of the Barratt analysis to low Froude numbers has been circumvented by Hogben[5] through his "steepness limitation", which is based on the premise that waves will only reach a certain steepness before breaking. Utilizing this pragmatic simplification, and Barratt's curve for a beam/length ratio of 0.5 in deep water, the wave drag curve may be taken out of its normalized form for a range of cases of interest; namely 150, 250, and 375 ton craft of 50 foot beam by 80 foot length. The results are shown in Figure 2-1.



W	D*
150	5,692
250	15,822
375	35,587

ℓ = 30'
b = 50'

Figure 2-1. Wave Drag vs Froude Number

Adding the momentum and aerodynamic drags (to be discussed in Section 4.1.2 of this report) the total drag shown in Figure 2-2 results. Note that all forms of water-contact drag have been neglected. From Newton's second law, the ACLV acceleration may be found:

$$T - \Sigma D = \frac{W}{g} a$$

where:

T	=	drawbar tension
ΣD	=	sum of all the drags
W	=	ACLV gross weight
g	=	Acceleration of gravity
a	=	ACLV acceleration

Drawbar tension is assumed to be constant at 20,000 pounds, the design capacity (as opposed to the 15,000 lb. for which the RH 53 is currently certified); and the acceleration, velocity, and displacement from the LASH ship are given by the following:

$$a_i = \frac{2 \times 10^4 - \Sigma D}{W/g}$$

$$v_i = a_i \Delta t + v_{i-1}$$

$$x_i = \frac{v_i + v_{i-1}}{2} \Delta t + x_{i-1}$$

These three equations are recursively solved, each time making use of the drag existing at velocity v_i. The results of the calculation (which was performed in 2-second increments) are shown in Figure 2-3, wherein the red lines represent velocity and the green lines represent distance from the LASH ship.

2.1.2 Discussion of Results

The effect of craft gross weight is evident. After 30 seconds, the lightest craft considered has reached 30 knots, the maximum design goal. The 250 and 375 ton craft are not likely to reach the design speed. The 250 ton craft would not be expected to exceed 14 kts, and the 375 ton craft

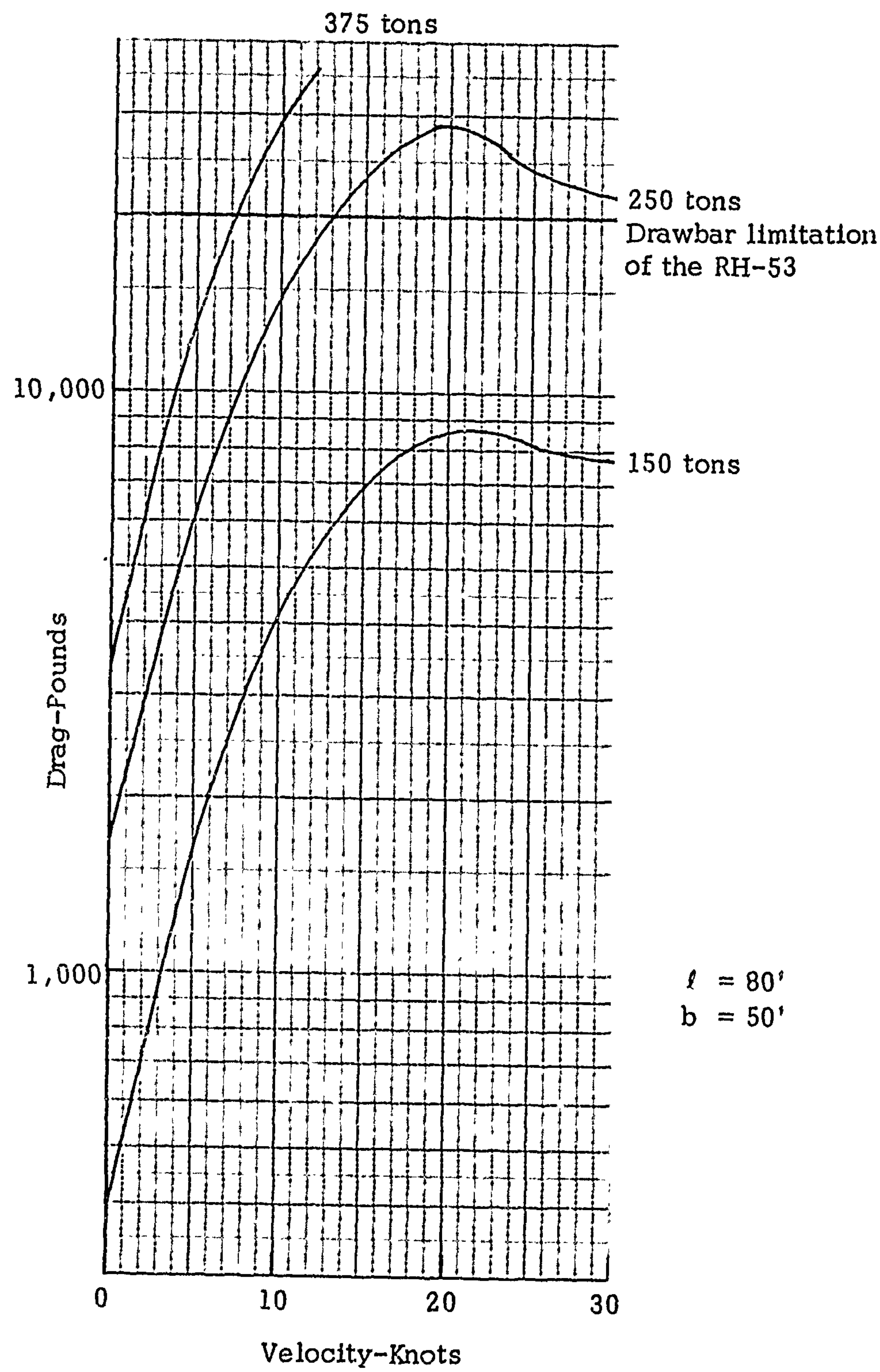


Figure 2-2. ACLV Total Calm Water Drag vs Velocity

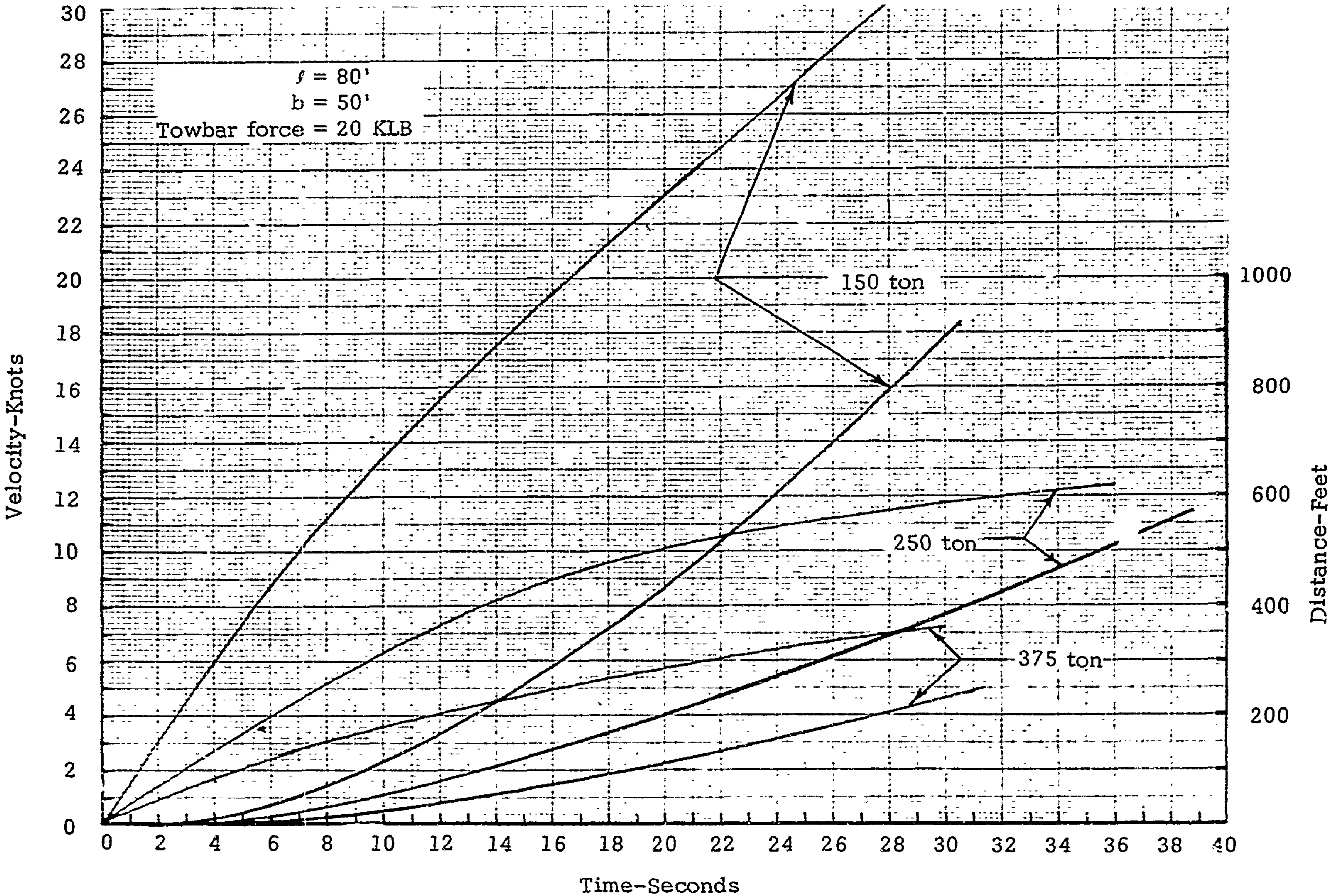


Figure 2-3. ACLV Velocity and Distance From LASH Ship vs Time From HELO Pickup

would not be expected to exceed 8 kts. Incorporating the range up the beach with the results reported herein, it is possible to predict, within the limitations imposed up to this point, how far various loads can be delivered up the beach. Figure 2-4 shows that loads of 150 ton can be easily delivered up the beach regardless of slope, but that 375 ton loads can only be delivered dry for beaches which are relatively flat. The 250 ton load, which is of particular interest, can be dry-delivered up a beach slope of 14°.

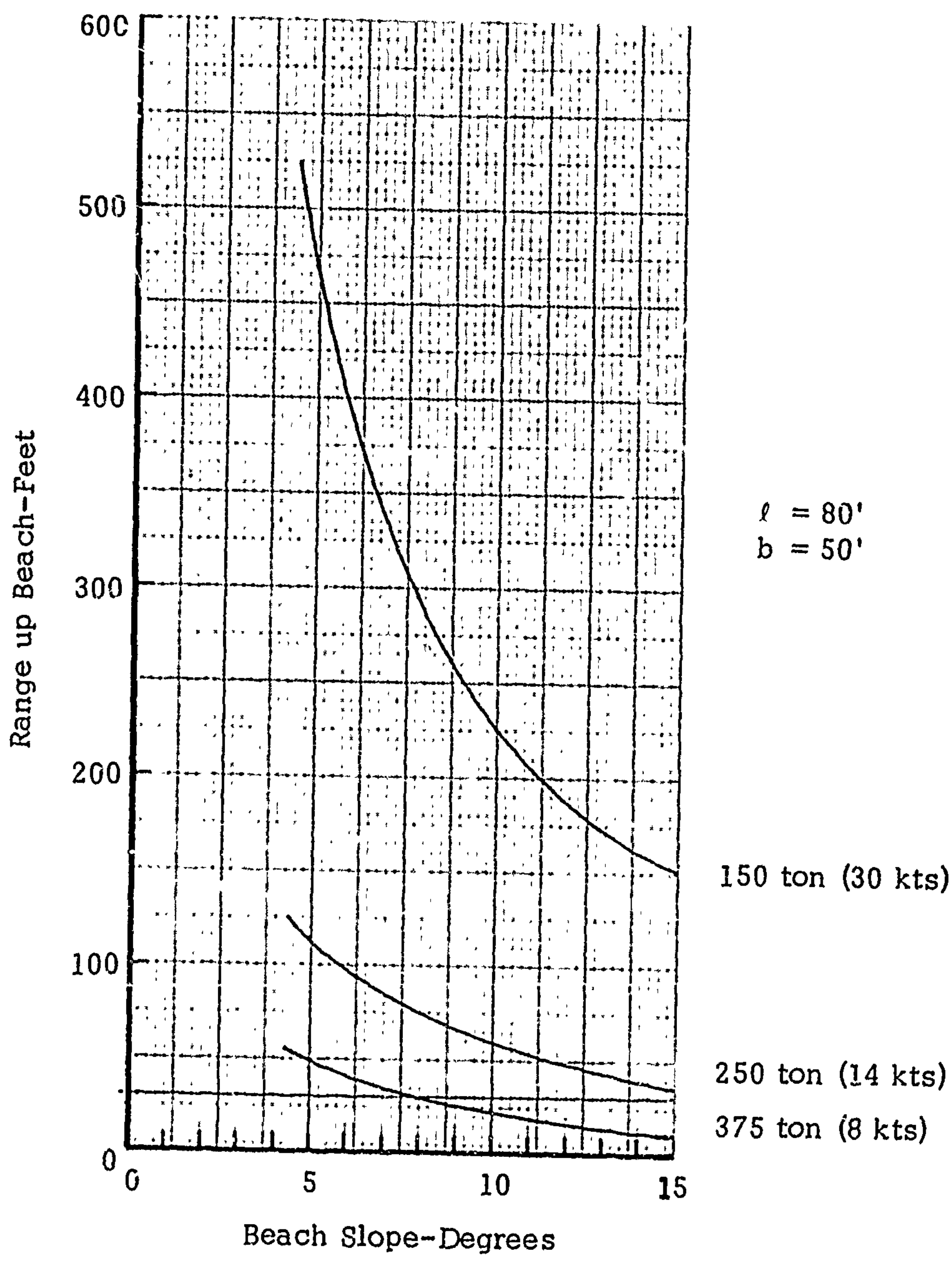


Figure 2-4. Range up Beach vs Beach Slope

Section 3

STABILITY AND CONTROL

Stability and control aspects generally receive a large share of the analyses involved with the design of surface effect vehicles. Most past work has been directed toward manned craft, and as such, the motions of an ACV are studied to ensure not only safe, but also comfortable transport. Those vehicles which have been designed primarily for cargo transport, even if unmanned, are typically limited to slow speeds and over land, ice, or calm water environments. Most notably, they operate at much lower cushion pressures and P/L ratios, which are analogous to aircraft wing loading. (see Table 3-1). The ACLV, however, requires hands-off stability in a very large vehicle moving over the open sea at moderately high speeds by aircraft tow — thus the problem is unique in many respects.

Table 3-1. ACV Working Pressure Comparison

CRAFT	P (lb/ft^2)	P/L
Jeff A	100	1.1 - 1.8
Jeff B	100	1.1 - 1.8
30' x 60' ACLV GW = 500	555	9.25
30' x 60' ACLV GW = 250	278	4.62
LASH and Skirt @ 250 tons	125	1.56
Hoverjack 1-15-15	63	1.58
Helibarge Hex-150	11	0.07
62' Square ACLV	130	2.1

A detailed review of many reports on existing designs has been conducted, with those relating to the Amphibious Assault Landing Craft (AALC) project being of particular interest. The papers reviewed address many aspects extrapolatable to the ACLV problem.

3.1 ANALYTICAL CONSIDERATIONS IN DESIGN OF THE ACLV FOR HANDS-OFF STABILITY

When an ACV deviates from the equilibrium state as a consequence of some disturbance, and the force and moments which a'e caused by this deviation *tend* to decrease it, then it is termed "statically stable". In manned craft, if the rate of growth of the deviation (which is exponential) is suffcierntly small, static instability can be acceptable. Dynamic stability, on the other hand, refers to the *transient* motion resulting from a disturbance. In this case, stability may not be a clear cut situation, and a dynamically stable vehicle may be unacceptable from a ride quality standpoint. The determination of vehicle stability is analytically pursued through the simultaneous solution of the six degree of freedom equations of motion which are based on Newton's second law. The problem is greatly simplified when symmetry exists, and linearization is frequently resorted to in order to decouple the motions. After these steps are followed, a matrix of force and force derivative coefficients is obtained, from which stability can be determined. These coefficients are found through wind tunnel and tow tank testing on a small scale model of the contemplated vehicle. Additional complication in the ACLV is presented by the force provided by the tow, which applies stabilizing rolling and pitching moments. The force is non-steady, and requires the considerations of the cable dynamics and helicopter dynamics for the complete solution. Sea state must also be an independent variable because it grossly affects drag, and can introduce large displacements, thereby violating the linearization assumptions.

The procedure to be followed is straightforward, and has been known since the early years of the aircraft industry:

1. Design a scale model
2. Wind tunnel, tow tank, etc., measurement of force coefficients
3. Data reduction
4. Stability calculation

The above represents an iterative process which is repeated until the desired vehicle performance is obtained. It may also require that modification be made to the full scale hardware after its testing in order to account for some aspects for which modelling was not possible.

Comparison with the Jeff AALC (the craft of most similarity to the ACLV) indicates that the ACLV can be made stable. Some instability, however, could be expected in operation at the hump speed. This is to be avoided from economic considerations as well as the stability, and experience has shown the instability to be no problem if the vehicle is accelerated through the hump. At large drift angles, the yawing moment may become destabilizing. The calculations of drift due to the cross wind, and the yaw angle which could result ($< 5^{\circ}$), is not likely to cause this instability, particularly when one considers the restoring force of the towline. Should the problem occur, a remedial measure could include the addition of a rudder at the stern of the ACLV. In so doing, one would have to reassess drag and roll stability. The existence of nonlinearities of the problem are suggested by the published comments that heave oscillation over land may cease once a forward velocity exists. Data is conflicting with regard to oscillatory motion over water. McGuire, et al,[6] states that oscillation of their barge was severe over water, but that a surface such as grass or sand broke up the oscillation. Trillo,[7] on the other hand, shows data for which damping is greater over water.

In summation, it can be said that the degree of stability must be determined by experience rather than any established analytical prediction method. Model tests must also be run, and the range of possible shift of parameters such as cushion geometry, CG, tow point, cable scope, etc., can then be found.

3.2 AN ESTIMATE OF THE EFFECT OF A 20-KNOT CROSSWIND ON THE ACLV

One of the design goals of the ACLV feasibility study is operation in a steady 20-knot crosswind. That which follows is an estimate of the sideslip resulting from the crosswind while under tow by a 20,000 drawbar force.

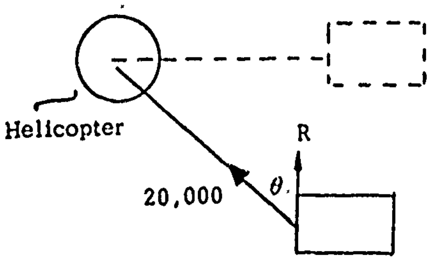
An analysis is based on the stepwise solution of Newton's second law, wherein the three acting forces are updated for each calculation. Namely, aerodynamic drag is updated in accordance with the wind relative velocity, wave drag with the actual sideslip velocity, and restoring component of the drawbar pull with sideslip distance. Calculations were performed on the MAR, Incorporated PDP9 computer for a range of variables of interest.

3.2.1 Analysis of the Problem

As was done in the estimate of delivery up the beach in Section 2.1, the "steepness limitation" of Hogben has once again been utilized. Under this simplification, the wave drag of Barrett is given by Figure 3-1 and the empirically determined equation $D^* = 0.253\ W^2$.

For the computer calculation, Figure 3-1 was fit by a suitable equation over the range of Froude Numbers to be encountered. ($D/D^* = 2.29\ F^{1.05} + 0.06$, $F \leqslant 0.3$).

Aerodynamic drag is computed in accordance with the customary $D = 1/2\ \rho V_{rel}^2\ AC_d$, where V_{rel} is the sideslip velocity of the ACLV relative to the 20 knot wind. As the ACLV sideslips as a result of the crosswind, the drawbar pull of the helicopter exerts a restraining force, $R = 2 \times 10^4 \cos \theta$.



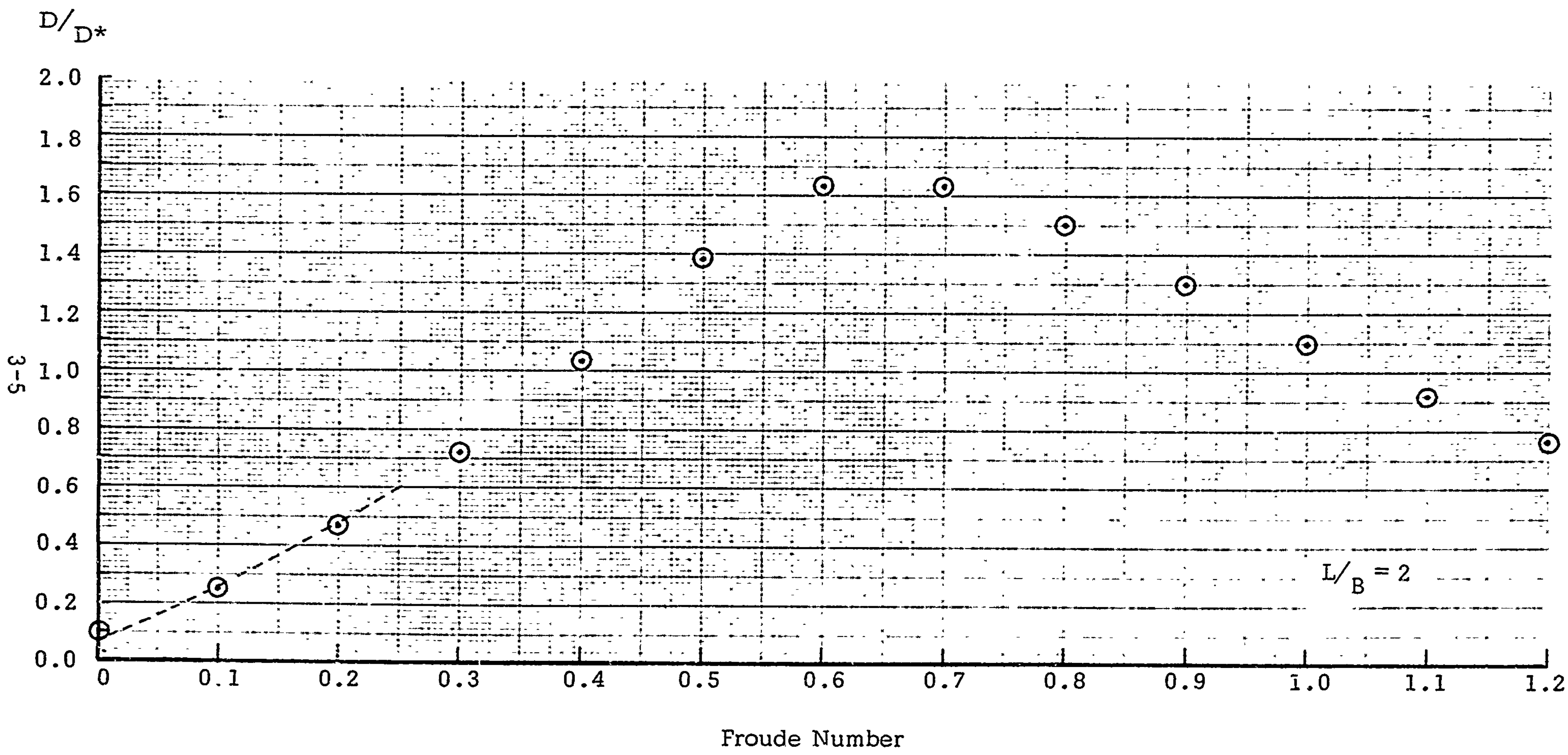


Figure 3-1. Calm Water Wave Drag

It was assumed that the helicopter flies at 60 feet above the tow point on the ACLV, and various scopes, S, of towcable up to 1000 feet were studied by taking the horizontal component of this force. These figures are based on conversations with Navy RH53 pilots having experience in the towing of sea-borne craft. The final restraining force is therefore $F = R \cos \phi$ where $\phi = \sin^{-1}(30/S)$. The equation of motion is:

$$a_i = \frac{-F - D_W + D_a}{W/g}$$

From the acceleration, the velocity and displacement are computed:

$$v_i = a_i \Delta t + v_{i-1}$$

$$x_i = \frac{v_i + v_{i-1}}{2} \Delta t + x_{i-1}$$

The FORTRAN IV program which successively solved the above, including the stepwise evaluation of the resultant force and the drags, appears in Figure 3-2. Finally, data for gross weights of 150, 250, 375 tons are evaluated for cable scopes of 400 through 1000 feet. A sample printout is shown in Figure 3-3, and Figure 3-4 contains the graphical results of a pair of computer runs for a 600-foot scope.

3.2.2 Results

The results indicate that the 20-knot wind poses no problem, particularly for shorter towcable lengths. For the design gross weight of 250 tons, Figure 3-5 shows the effect of scope variations. For this design weight, the sideslip is of the order of one ACLV length, and not a problem.

```
      INTEGER TFINAL,DELTAT,T
      READ(1,1) B,W,AREA,CD,SCOPE
      READ(1,2) TFINAL,DELTAT
      WRITE(1,3)
      WRITE(1,4)
      I=0
      V=1E-5
      VI=0.
      XI=1E-5
      DSTAR=.253*V*W
      DO 50 T=1,TFINAL,DELTAT
      D=DELTAT
      F=V/SQRT(32.2*B)
      DWAV=DSTAR*2.29*F**1.05+.06
      VREL=33.8-V
      DAERO=1.19E-3*VREL**2*AREA*CD
      Y=SQRT(SCOPE**2-XI**2)
      ANGL=ATAN(Y/(X+1E-3))
      ANGLE=ATAN(60./SQRT(SCOPE**2-60.**2))
      R=2E4*COS(ANGLE)*COS(ANGL)
      A=32.2*(-R-DWAV+DAERO)/(W*2E3)
      V=A*D+VI
      VI=V
      X=(V+VI)/2.*D+XI
      XI=X
      I=I+1
      IF(V-0.) 40,40,10
10    CONTINUE
      IF(I-2) 50,20,20
20    VKT=V/1.69
      WRITE(1,5) T,X,V,VKT,A
      I=0
50    CONTINUE
      GO TO 6
1     FORMAT(2F4.0,F5.2,F4.3,F5.0)
40    WRITE(1,5) T,X,V,VKT,A
2     FORMAT(2I4)
3     FORMAT(52H TIME    DISTANCE    VELOCITY
     1VELOCITY    ACCEL)
4     FORMAT(51H SEC     FEET        FT/SEC
     1KNOT        FT/SEC2)
5     FORMAT(I14,F11.2,F13.2,F12.2,F10.2)
6     PAUSE
      STOP
      END
```


Figure 3-2. Computer Program for Determination of Sideslip

TIME SEC	DISTANCE FEET	VELOCITY FT/SEC	VELOCITY KNOT	ACCEL FT/SEC2
2	0.27	0.18	0.10	0.09
4	0.86	0.33	0.20	0.08
6	1.74	0.47	0.28	0.07
8	2.87	0.59	0.35	0.06
10	4.22	0.72	0.41	0.05
12	5.75	0.79	0.47	0.04
14	7.45	0.86	0.51	0.04
16	9.27	0.93	0.55	0.03
18	11.20	0.98	0.58	0.02
20	13.21	1.01	0.60	0.02
22	15.27	1.04	0.62	0.01
24	17.38	1.06	0.63	0.01
26	19.51	1.07	0.63	0.00
28	21.65	1.07	0.63	-0.00
30	23.78	1.06	0.63	-0.00
32	25.89	1.05	0.62	-0.01
34	27.97	1.04	0.61	-0.01
36	30.01	1.01	0.60	-0.01
38	32.00	0.99	0.58	-0.01
40	33.93	0.96	0.57	-0.01
42	35.80	0.93	0.55	-0.02
44	37.61	0.89	0.53	-0.02
46	39.34	0.86	0.51	-0.02
48	41.01	0.82	0.49	-0.02
50	42.59	0.78	0.46	-0.02
52	44.10	0.74	0.44	-0.02
54	45.52	0.70	0.42	-0.02
56	46.87	0.66	0.39	-0.02
58	48.14	0.62	0.37	-0.02
60	49.33	0.59	0.35	-0.02
62	50.44	0.55	0.32	-0.02
64	51.48	0.51	0.30	-0.02
66	52.44	0.47	0.28	-0.02
68	53.33	0.43	0.26	-0.02
70	54.14	0.40	0.24	-0.02
72	54.89	0.37	0.22	-0.02
74	55.57	0.33	0.20	-0.02
76	56.19	0.30	0.18	-0.02
78	56.75	0.27	0.16	-0.01
80	57.25	0.24	0.14	-0.01
82	57.69	0.22	0.13	-0.01
84	58.09	0.19	0.11	-0.01
86	58.43	0.17	0.10	-0.01
88	58.72	0.14	0.08	-0.01
90	58.98	0.12	0.07	-0.01
92	59.19	0.10	0.06	-0.01
94	59.36	0.08	0.05	-0.01
96	59.50	0.06	0.04	-0.01
98	59.60	0.05	0.03	-0.01
100	59.68	0.03	0.02	-0.01
102	59.72	0.02	0.01	-0.01
104	59.75	0.01	0.00	-0.01
106	59.74	-0.00	0.00	-0.01

Beam = 50 ft
Weight = 250 ton
Area = 1200 ft^2
C_d = 0.86
Scope = 800 ft
Altitude = 60 ft

PAUSE 000000

Figure 3-3. Computer Printout for a Typical Configuration

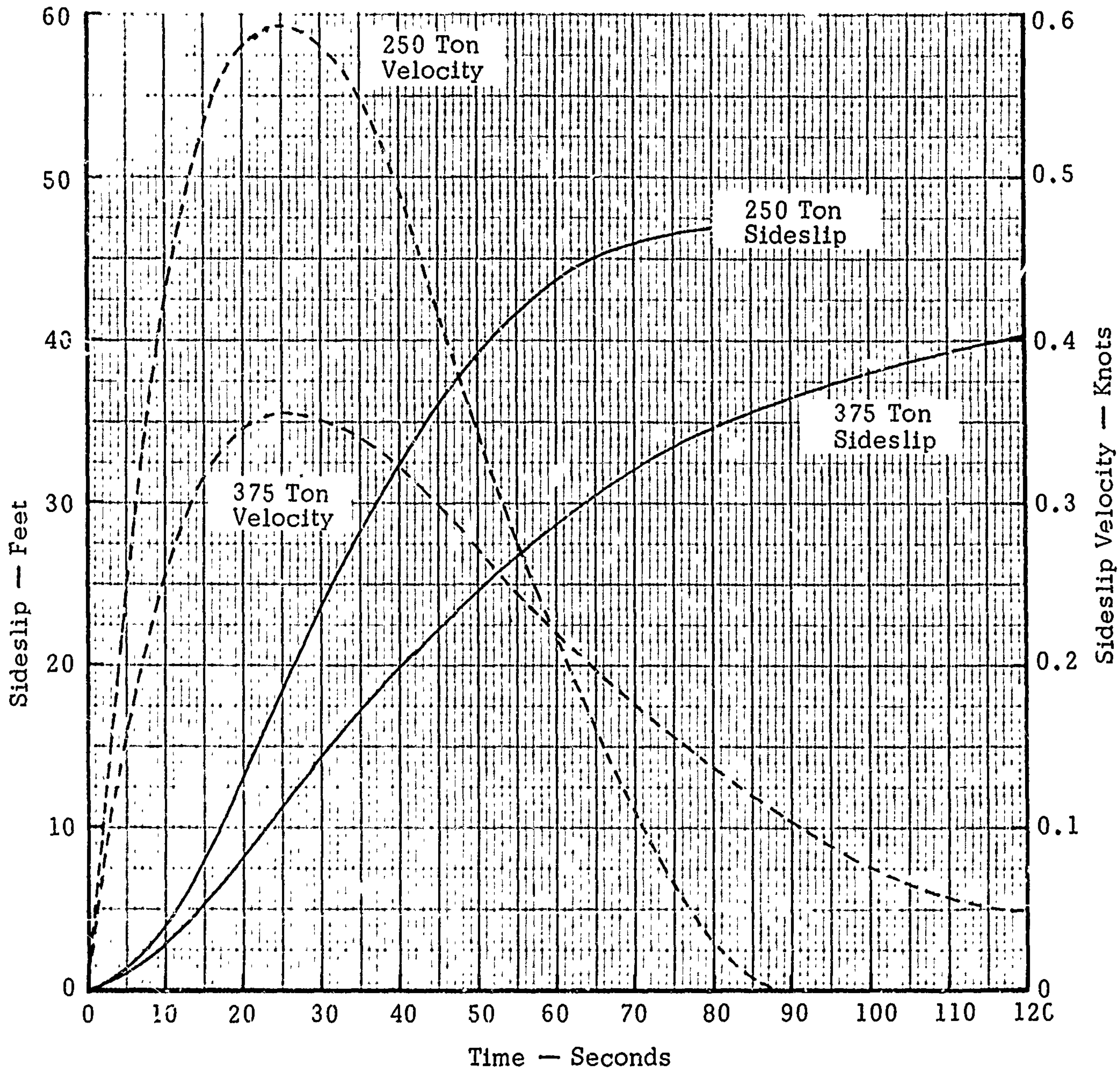


Figure 3-4. Sideslip and Sideslip Velocity as Functions of Time

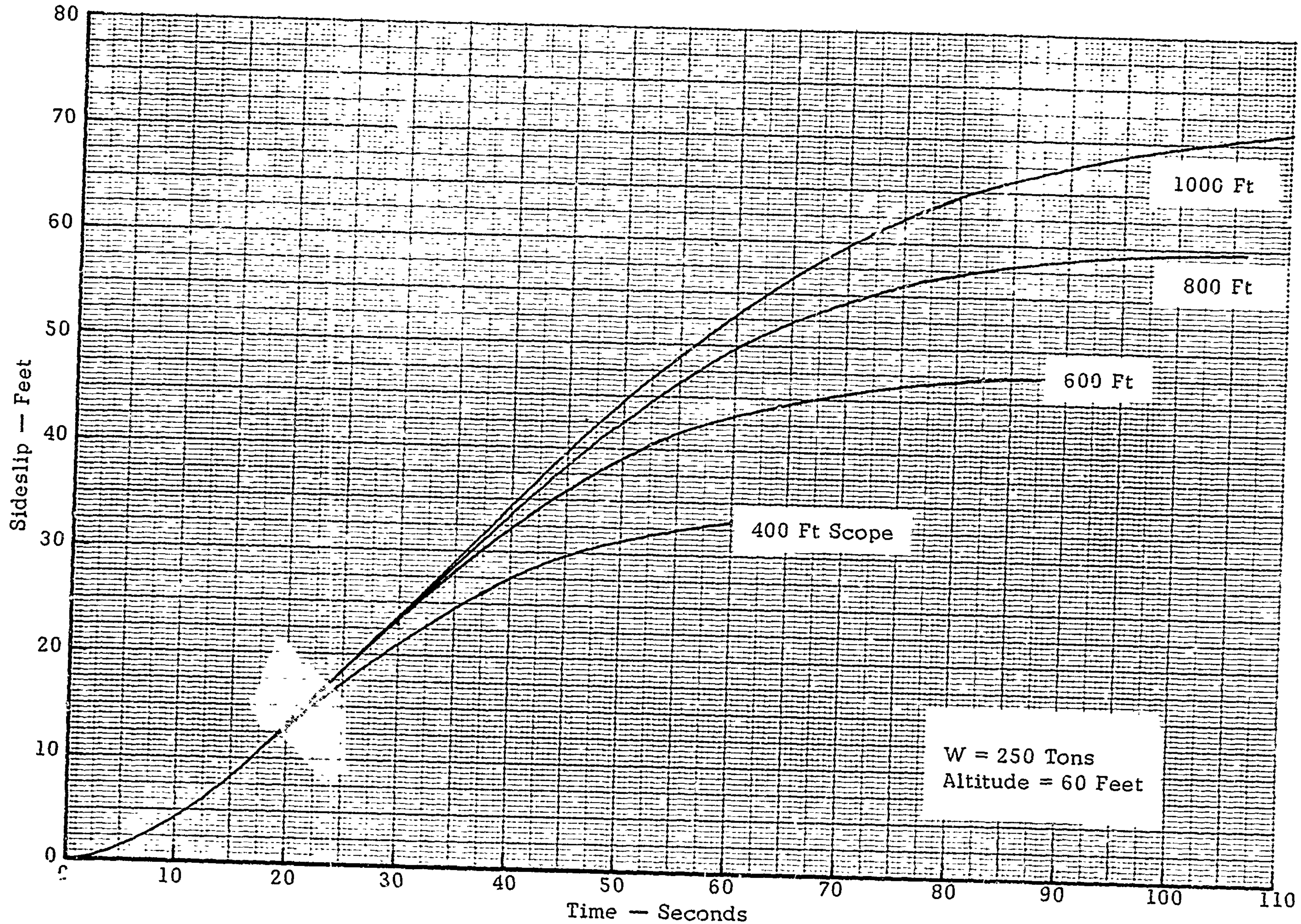


Figure 3-5. Sideslip as a Function of Time for Various Tow Cable Scopes

Section 4

LIFT ENGINEERING PLANT

Prior to investigation of specific engine and fan combination selections, a determination of ACLV system flow rate requirements must be concluded. Contained within this section is a discussion of drag. The reason for this apparent organizational anomaly is that the prime contributor to the lift fan problem is wave drag, and this is strongly dependent on cushion pressure, upon which power is heavily dependent.

4.1 A REVIEW OF AIR CUSHION POWER REQUIREMENTS FOR THE ACLV

This section presents the results of preliminary calculations aimed at determining the basic feasibility of the ACLV. Calculations are presented for a load of LASH lighter dimensions as a baseline, and a load-area of ACLV dimensions. The results of these calculations attest to the feasibility of the concept, provided that a cushion size on the order of the ACLV is used.

4.1.1 The Cushion System

The weight flow (w) of the system is determined by the peripheral area through which the cushion air escapes with discharge velocity (V_d):

$$w = AV_d k \rho g \qquad \text{lb/sec}$$

where

A = peripheral area, $2(\ell + b)h$
ℓ = cushion length, ft
b = cushion beam, ft
h = air gap, ft
k = discharge coefficient
V_d = discharge velocity, ft/sec
ρ = air density, slug/ft^3
g = acceleration of gravity, ft/sec^2

The discharge coefficient will vary with skirt geometry and clearance height of the skirt, but it is assumed herein that $k = 0.5$. Through Bernoulli's equation, the weight flow may be related to a more meaningful parameter, cushion pressure (P_c):

$$w = Agk.\sqrt{2\rho P_c}$$

Alternatively, this may be expressed in terms of gross weight (W) and cushion area (S).

$$w = Agk \sqrt{2\rho}\left(\frac{W}{S}\right)^{1/2}$$

The power consumed in maintaining the craft on cushion is

$$P = \frac{PQ}{550} \quad , \text{hp}$$

$$= 0.052 \left[(\ell + b)h\right]\left(\frac{W}{S}\right)^{3/2}$$

The relationship is plotted in Figure 4-1 for the dimensions of the lighter itself and skirt clearances of 1", 2", and 3". Trillo[7] indicates that lift horsepower for existing craft is nominally 35 to 45 shp/ton gross weight. The horsepower required, which has been calculated according to the preceding equation, neglects ducting losses, and therefore shows power requirements which are lower than current craft. Wave pumping requirements have also been neglected, also resulting in lower horsepower than current practice suggests. Once a preliminary configuration has been adopted, the calculations can be refined to take ducting losses into account.

4.1.2 Drag Classifications

The shape of the lighter is such that aerodynamic drag is likely to be of some concern. Spray and viscous drag will be neglected at this time due to the uncertainty of prediction methods for them. The major drag contributor will be the wave drag arising from the high cushion pressure necessary to support the barge.

4.1.2.1 Aerodynamic Drag. Hoerner[8] asserts that for a rectangular shape in proximity to a plane, the drag coefficient based on frontal area is $C_d = 0.86$. The addition of a seal may actually serve to reduce this value of C_d slightly.

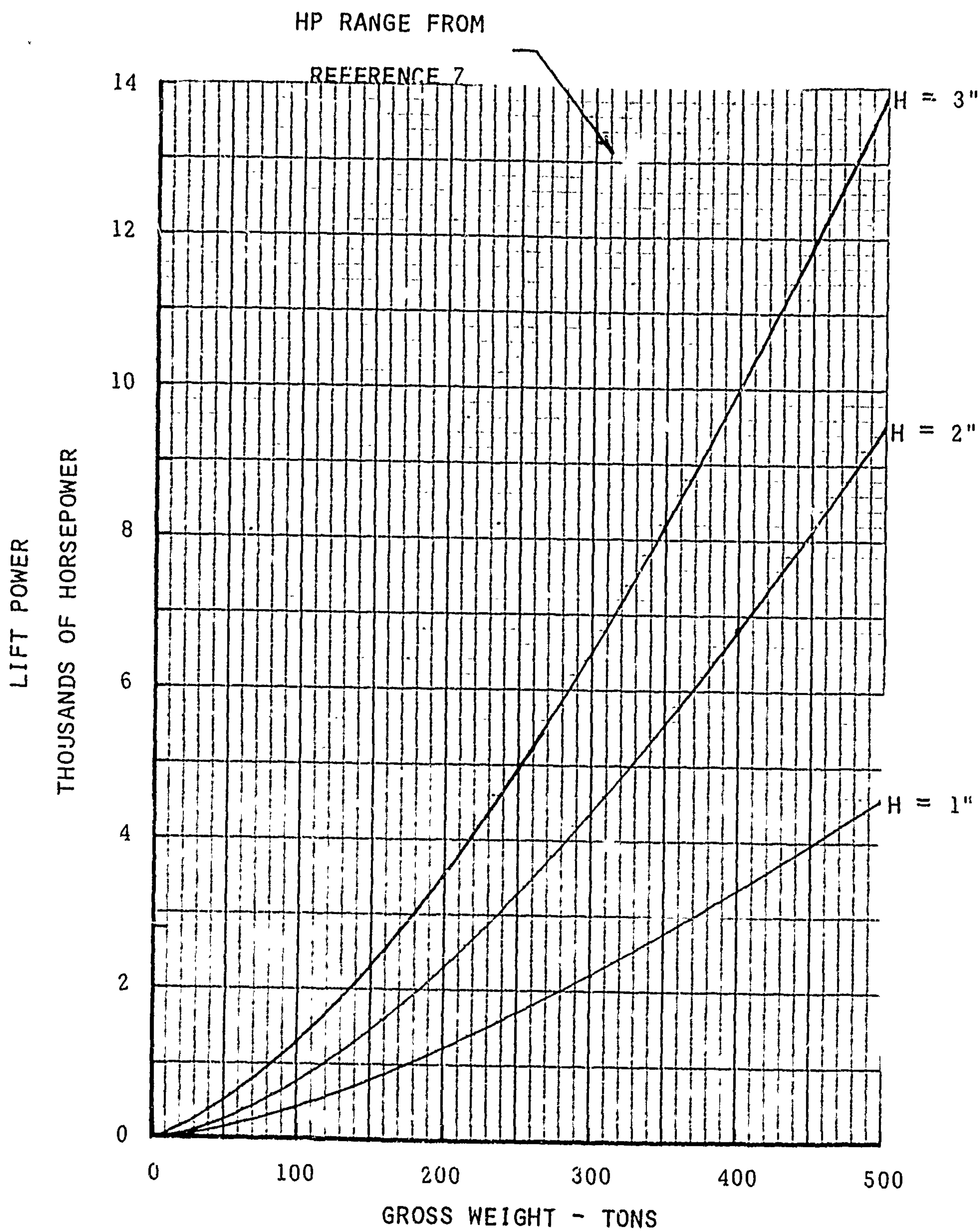


Figure 4-1. Lift Power Required to Raise Various Gross Weights to Specific Skirt Clearance Heights

The drag is given by:

$$D = 1/2 \rho V^2 AC_d$$

The frontal area (A) consists of the 13' x 31.16' of the lighter, plus that posed by the seal. It is assumed that the seal height is 6 ft, assuring easy clearing of a 1 foot obstacle, as well as potential for sea-worthiness in wave heights of 6 feet. The resulting graphical representation of drag is shown in Figure 4-2. Note that it is less than 10 percent of the drawbar force, and should not be a governing factor.

4.1.2.2 Momentum Drag. This is the drag associated with bringing the still, ambient air entering the lift system up to the speed of the vehicle. The governing equation is plotted on Figure 4-2 for h = 3", considered to be a worst case:

$$D_M = \rho Q_d V$$

The momentum drag is of the order of the aerodynamic drag in the worst case. Actually, the seal clearance is expected to be approximately 1 inch, and the momentum drag is therefore 1/3 that shown in Figure 4-2.

4.1.2.3 Wave Drag. The wave drag is that which results from the pressure cushion displacing water as the cushion traverses the water surface. Theoretical predictions for rectangular platforms have been made by Barratt[3] for various Froude numbers, water depths, and beam/length ratios. His results have been substantiated by the experimental findings of Everest,[9] and Everest and Hogben.[10] The same authors, in Reference 11, later deduced limitation boundaries for induced wave drag, since waves will only reach a certain steepness before breaking down. As a consequence, the high theoretical values of Barratt may not exist in practice. Until further study is complete, however, the results of Barratt will be used to provide an upper bound. More refined analysis is also possible using the method of Doctors and Sharma,[4] but that technique is cumbersome for preliminary studies. Figure 4-3, which is based on the results of Barratt, raised what appeared to be the first serious question

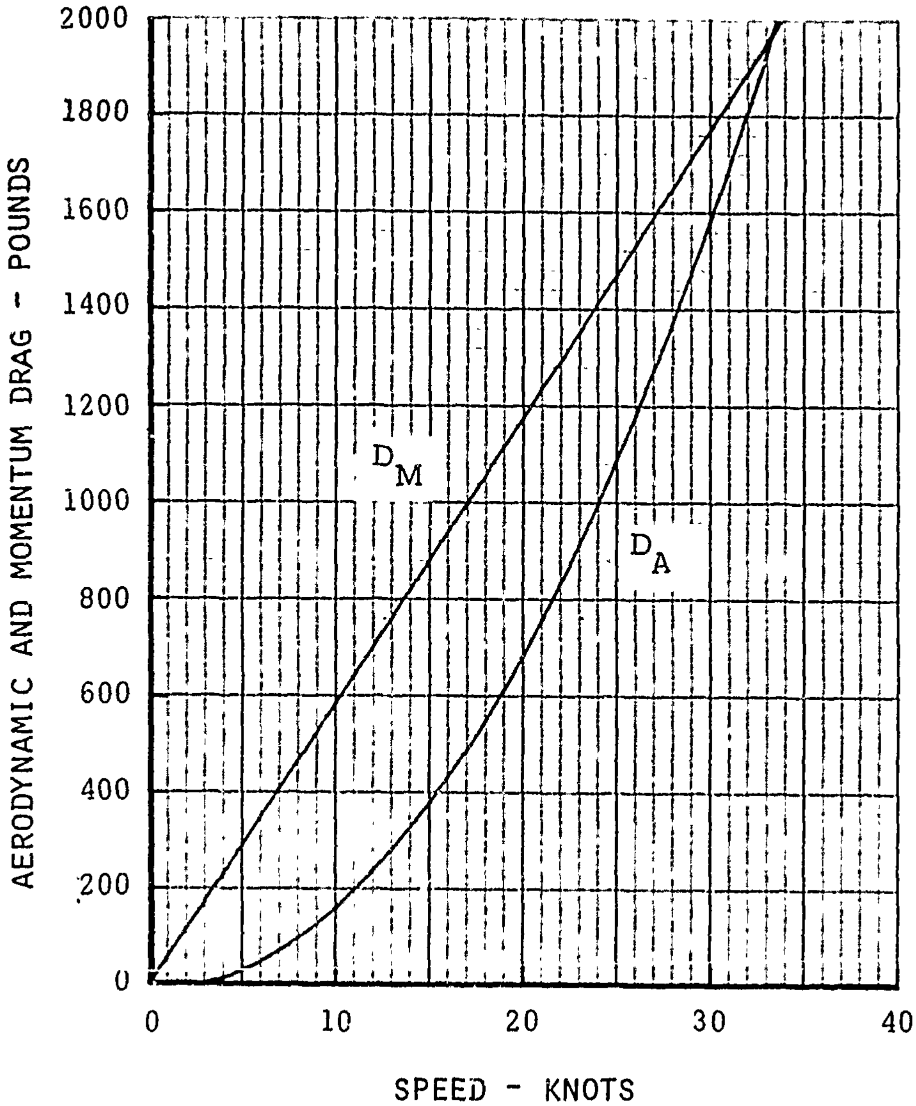


Figure 4-2. Aerodynamic and Momentum Drags for an Air Cushion Supported ACLV Using LASH Lighter Dimensions

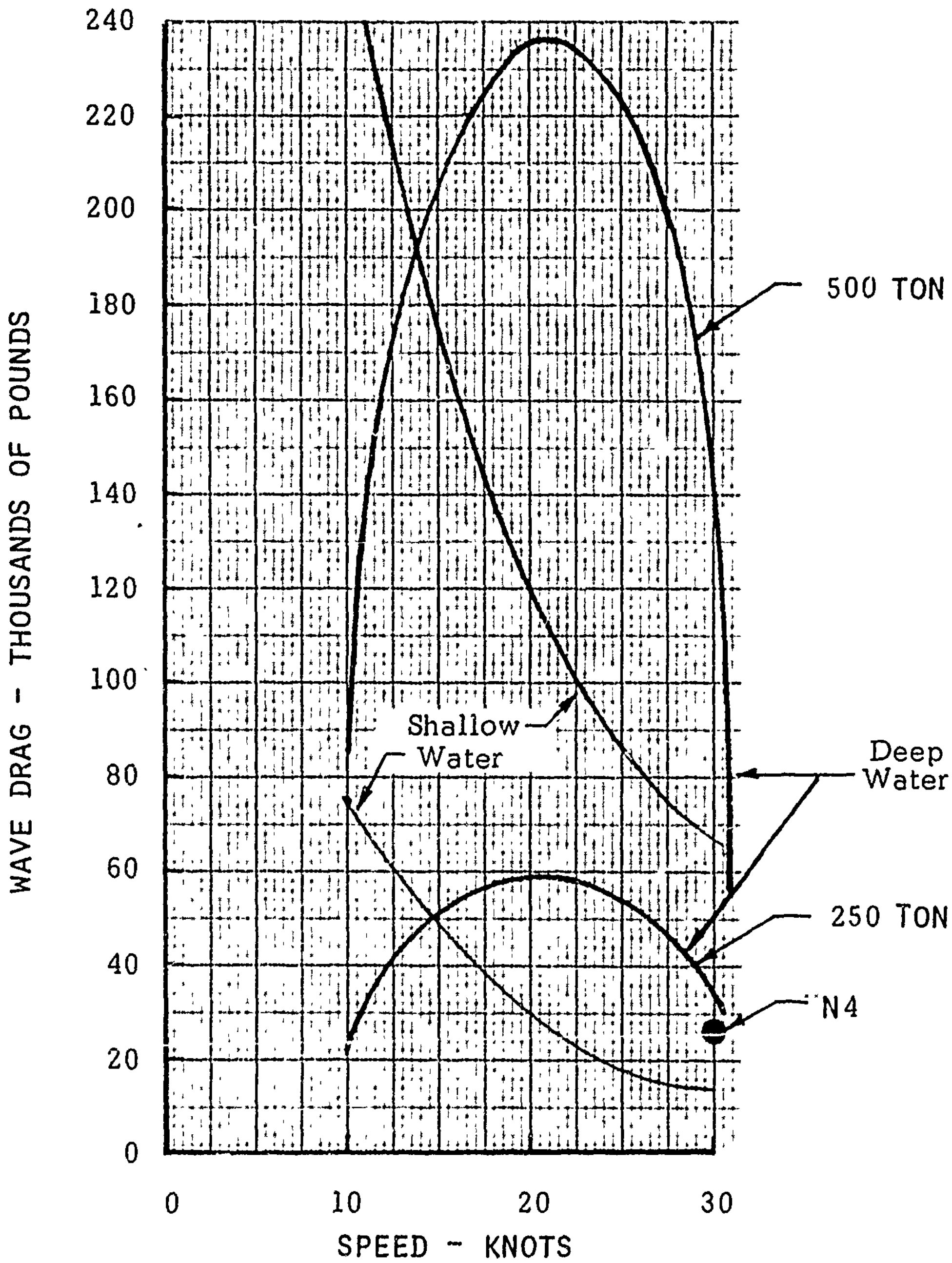


Figure 4-3. Wave Drag for an Air Cushion Supported ACLV Using LASH Lighter Dimensions

to the feasibility of the ACLV. The validity of these drag figures is corroborated by Figure 4-4, reproduced from Reference 7. Note the data point N4. This is for a 200 ton craft, with a cushion pressure of 50 psf. Its ratio of resistance to displacement is 125, resulting in a drag of 25,000 lb. This point is indicated on Figure 4-3, falling immediately below the 250 ton calculation for deep water. Two other sets of data form the main substance of Figure 4-3. They have been derived for the displacements (i.e., gross weight) of 500 and 250 tons. It is this result that led to consideration of the 250 ton maximum gross weight.

Figure 4-4 shows the original 500 ton craft on a 30 ft x 60 ft cushion and the 250 ton craft on a 50 ft by 80 ft cushion. Note that this latter configuration is then in the vicinity of the state-of-the-art technolology.

4.2 DUCTING LOSSES AND THEIR EFFECT ON ACLV POWER AND FLOW REQUIREMENTS

This section consists of a set of preliminary calculations which enable an estimation of the horsepower requirements of the lift fan system. The cushion pressure is given by:

$$P_c = \frac{W}{A} = \frac{250\ (2000)}{50\ (80)} = 125\ \mathrm{lb/ft^2}$$

The air gap, or daylight clearance, between the skirt and the ground is one inch, providing, in turn, an efflux area of 21.67 feet. The weight flow of air through this gap arising from the cushion pressure is:

$$\begin{aligned} w &= Agk\sqrt{2P_c\rho} = 21.67\ (32.2)\ (0.5)\sqrt{2\ (.0024)(125)} \\ &= 270\ \mathrm{lb/sec} \\ &= 3554\ \mathrm{ft^3/sec} \end{aligned}$$

The pressure drop is given by:

$$\Delta P = \frac{1}{2}\rho V^2\left(f\ \frac{L}{d} + \Sigma H_L\right)$$

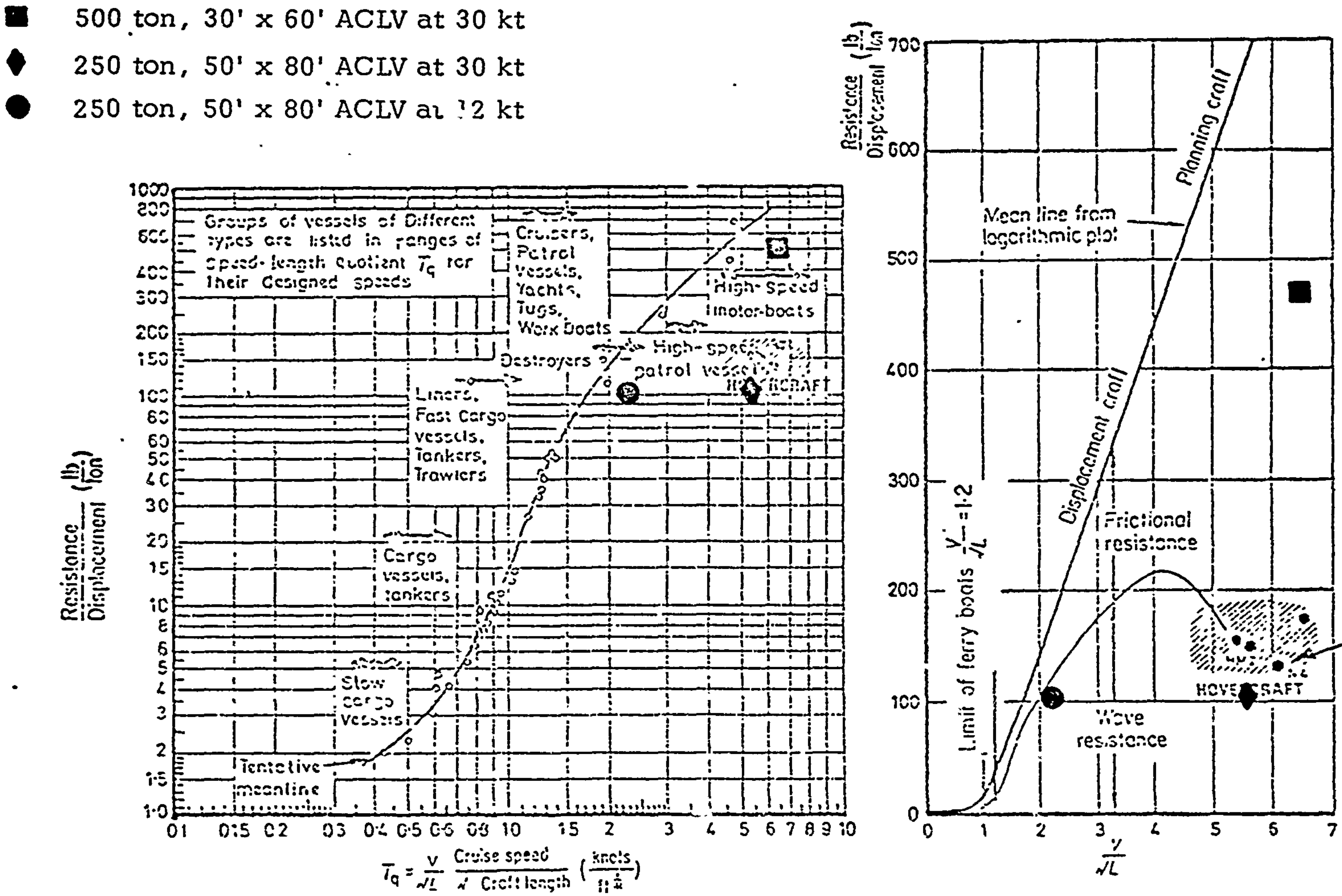


Figure 4-4. Operating Characteristics of Current Hovercraft Over Water

where:

ΔP	=	pressure drop, lb/ft^2
f	=	friction factor, $f = f(R)$
L	=	pipe length, ft
d	=	pipe diameter, ft
ΣH_L	=	sum of head losses from bends, area changes, etc.

The ducts, according to Goodyear, are 2.55 ft diameter, and flow through each of them is 174 ft/sec.

The Reynolds number is

$$R = \frac{VD}{\nu} = \frac{174\ (2.55)}{160 \times 10^{-6}} = 2.8 \times 10^6$$

The flow is turbulent, and from the Moody diagram[12] for smooth pipe, $f = 0.008$. Assuming a single elbow ($H_L = 0.3$) and an abrupt enlargement as the duct feeds the plenum ($H_L \leq 1$), a "Y" ($H_L = 1$) and a 45° bend ($H_L = (0.4)(0.65)$).

$$\Delta P = 35.6\ (0.008 \frac{L}{d} + 0.3 + 1 + 1 + (.4)(.65))$$

Assume $\ell = 50$ ft, which conservatively accounts for whatever ducting may be required in the final configuration.

$$\Delta P = 35.6\ (0.008 \left(\frac{50}{2.55}\right) + 2.56) = 96.7\ lb/ft$$

The total pressure which must be supplied by the lift fan is $125 + 97 = 222\ lb/ft^2$.

The power required is

$$P = \frac{222\ (3554)}{550} = 1434 \text{ hp}$$

In the case of the packable system, where the lift engineering plant pressurizes the trunk or frame to 4 psi (prescribed by Goodyear) which in turn bleeds air to provide cushion pressure, the power becomes:

$$P = \frac{4(144)(3554)}{550} = 3722 \text{ hp}$$

With the increase in horsepower comes the advantage of having a reserve volume which can feed the skirt and improve stability.

Section 5

COST AND PERFORMANCE COMPARISON

The alternative approaches described in Reference (2) were evaluated and reduced to two viable systems. Those systems, a packable version and a rigid flatbed, differ considerably in mechanization. A third system, which is a derivative of the rigid version, was also evaluated since it shows promise of the lowest cost and greatest potential for improvement in control and stability aspects.

5.1 THE PACKABLE SYSTEM

The packable system shown in Figure 5-1 is essentially an inflatable framework or trunk to which the seal is attached. The frame-seal assembly is intended to be transported in a deflated and packaged state, then inflated and the LASH lighter emplaced at the off-shore point of destination. The lift engineering plant will be attached to the LASH lighter at either the embarkation port or the destination. Attachment of ducts and fueling would be done after the frame is inflated and the lighter emplaced.

5.1.1 Trunk and Seal Assembly

When deflated and packed for transport, the trunk and seal assembly will take little room, and therein lies its greatest advantage. When inflated for LASH lighter emplacement however, it becomes quite bulky. System design dictates trunk diameters on the order of ten feet in order to provide the necessary stiffness, flotation and cushion area. The large expanses of specialized fabrics, and the relatively expensive manufacturing and assembly techniques will result in the packable system being more expensive to buy than a rigid system.

Since the packable system must be designed around the physical characteristics of the LASH lighter, it will have limited ability to transport other loads. The resulting form factor and materials used in the trunk and seal assembly will result in a certain susceptibility to damage in transit and handling, thereby reducing the likelihood that it could be used more than once for each amphibious operation.

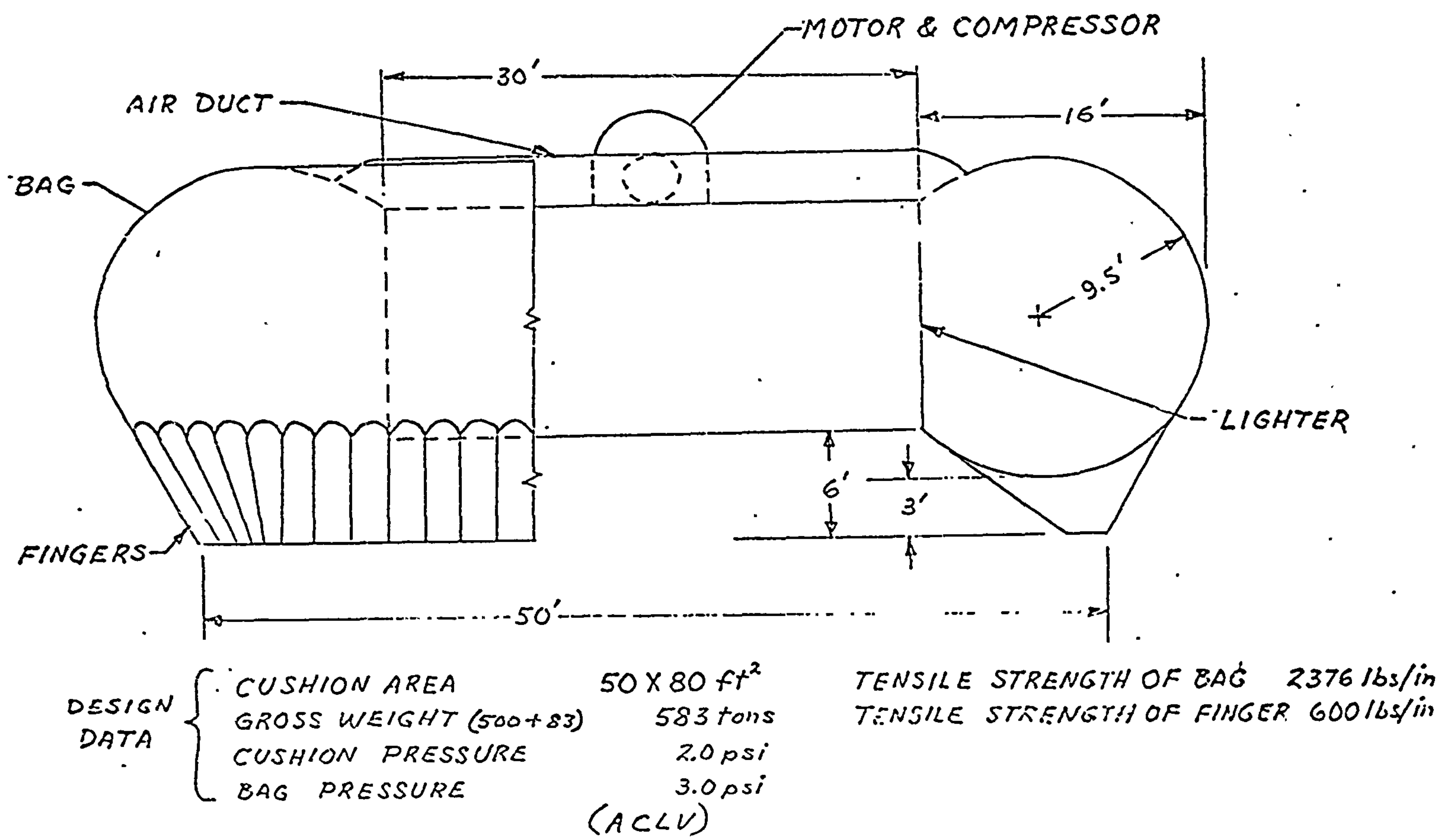


Figure 5-1. Packable Seal Configuration Concept C End View
(Goodyear Aerospace Corp.)

5.1.2 Lift Engineering Plant

Since the lift engineering plant must be compact and light enough to be physically attached to the lighter rather than the inflated frame, the use of a gas turbine is virtually dictated. Although the gas turbine is compact, light and in common usage among high performance manned surface craft, it has one overriding disadvantage to ACLV application; that of cost.

In order to arrive at representative costs for a suitable gas turbine lift engine, the Garrett Corporation was contacted for information regarding commercially available engines. To minimize costs, the application was described and a non-man rated unit was specified. The obvious choice for the turbine is one which has been designed for providing bleed air. Using a unit such as the Garrett Model GTCP 660-4R (see data sheet included in Appendix A) with a flow multiplier, ample air can be provided at the pressure necessary to support the load. This particular engine also has a shaft output which is adequate to drive a small compressor that is required to inflate and maintain the trunk of the cushion at the higher pressures recommended by Goodyear. The GTCP 660-4R costs were quoted as $175,000 each, plus the cost of the flow multiplier. Garrett was the only gas turbine supplier contacted; however, they stated that an industry rule of thumb for the cost of non-man rated turbine engines is approximately $100.00 per hp.

Based upon these figures, plus the projected costs provided by Goodyear for the frame-skirt assemblies, it is estimated that the packable system costs could approach $1.0 million each.

5.2 THE RIGID SYSTEM

The rigid system concept, shown in Figure 5-2, consists of a load-bearing flatbed to which the seal and lift engineering plant are permanently affixed. These systems would be stacked in the aft section of the LASH ship. As with the packable system, the lighters would be emplaced at the off-shore point of destination.

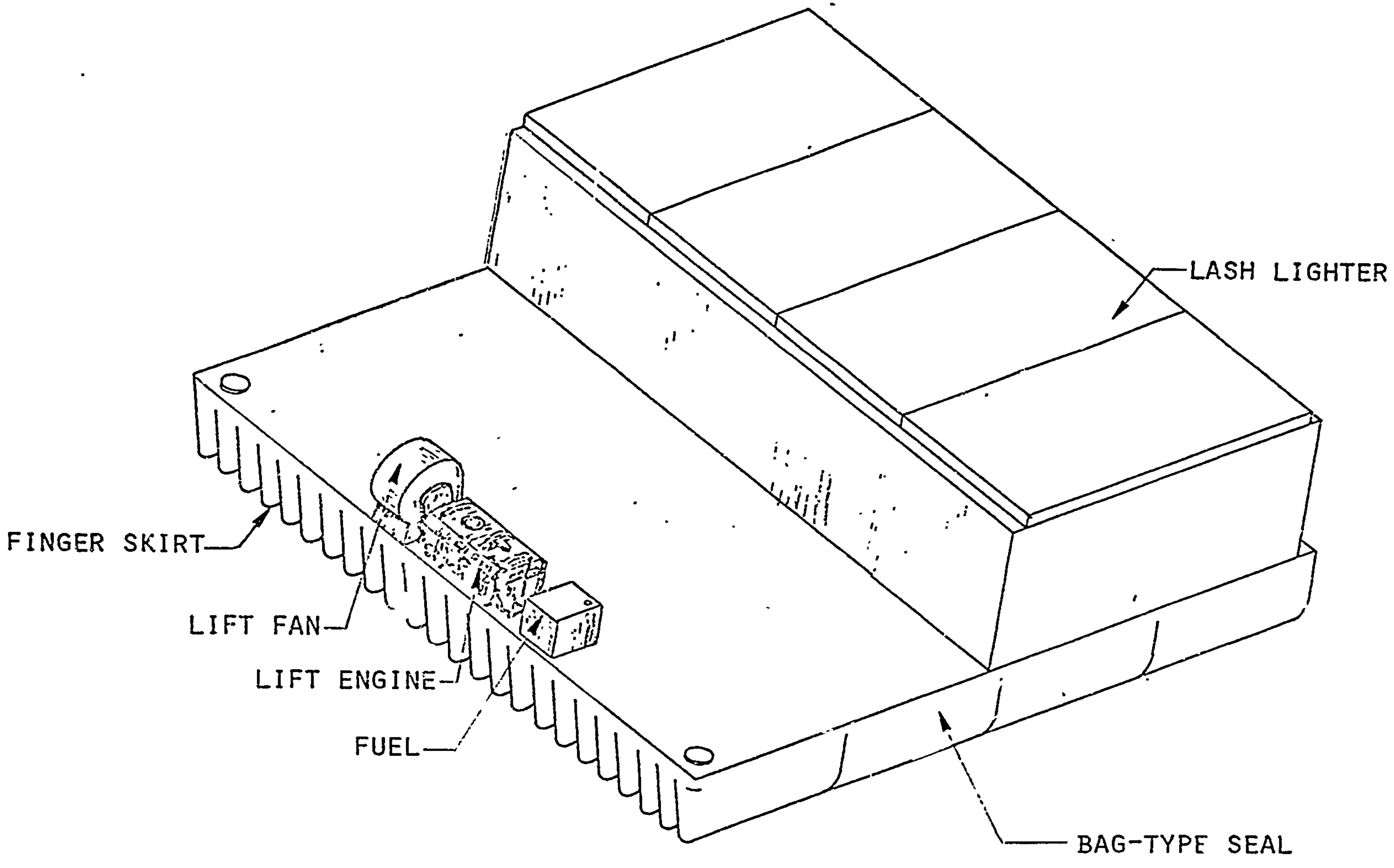


Figure 5-2. ACLV Rigid System Concept

5.2.1 Platform and Seal Assembly

Since this approach is centered about a rigid flatbed platform, it shows promise of being much more versatile. The system can be reused many times during a given operation, thus requiring fewer systems, and can accommodate loads other than the LASH lighter.

5.2.1.1 Fabrication of the Rigid Structure. Representative costs for fabrication of the hard structure portion of the rigid system were arrived at by discussion with Avondale Shipyard, the building yard for LASH ships and lighters. Mild carbon steel currently costs approximately $300.00 per ton. Exotic steel or aluminum alloys will cost up to three times that of the above figure. Fabrication costs for non-complex structures of mild steel approximate 50 man-hours per ton. Man-hours for exotic materials such as HY-80 steel range up to 250 mh per ton; however, less of it is generally used since it is usually lighter than mild steel. A very rough estimate of total materials and labor for non-complex fabrication in mild steel was given as $1,000 to $1,500 per ton. A non-rigorous structural analysis was conducted for the ACLV platform, and based upon the results, an estimate of hard structure weight was 20 tons. Consequently, the estimated range of cost is $20,100 to $30,150 for ACLV hard structure fabrication in mild steel.

5.2.1.2 Seal Costs. Since a rigid load bearing structure is assumed for this approach, the use of specialized fabrics can be minimized. Only the front seal need be finger type. The side and rear seals may be of one-piece construction. Because it is anticipated that a rigid system will be reused several times during any given operation, the seal material must be of higher cost and survivability; however, since less of it is used and attachment is less complex, cost of the vehicle should not be strongly affected. The cost of a seal such as that shown in Figure 5-2 is estimated to be $178,000 by Goodyear.

5.2.2 Lift Engineering Plant

Perhaps the most dramatic cost savings lies in the lift engineering plant. The flatbed area will be approximately twice that of a LASH lighter in order to arrive at workable cushion pressures, and there remains open deck area. The lift engineering plant can be mounted to the flatbed, and thus can be heavier and bulkier than one which must be mounted to the load. An adequate lift plant can be assembled of commercially available, relatively low cost components. Representative sources were contacted for information with the following results.

5.2.2.1 Centrifugal Fan. Buffalo Forge Corporation was contacted as a source for a large centrifugal fan. Their Model 1085 fan with the appropriate accessories will supply the correct air flow. The total weight of the fan and accessories is 7192 pounds, occupying an approximate 10 ft cube of space. It is estimated that approximately 1300 bhp would be required to drive this unit at its rated output. The cost will be $21,800, plus $.25/lb for galvanizing, if desired. A delivery schedule of 20 to 35 weeks was quoted. The Model 1085 fan is available with a variable pitch feature which may be useful if dynamic control is used in the future. The cost of this feature is an additional $6,000.

5.2.2.2 Lift Engine. Detroit Diesel Division of General Motors was contacted for information on lift engine parameters. They market a two stroke cycle diesel engine which is claimed to be approximately one third lighter than four-stroke cycle engines of comparable output. Detroit Diesel Model No. 16V-149T is rated at 1325 continuous bhp. This engine weighs 10,840 lbs with appropriate accessories, and occupies a space 9 feet x 5 feet. Fuel consumption is estimated at 83 gph. The cost for this engine (with compressed air start and fresh water cooling) is $60,565. The Buffalo Forge Model 1085 fan is rated at 1780 rpm and the Detroit Model 16V-149T engine is rated at 1900 rpm. Either a simple chain drive or direct coupling will be fully adequate.

5.3 SEMI-RIGID SIDEWALL

This concept, shown in Figure 5-3, is similar to the rigid system described under Section 5.2, with one exception. This concept uses rigid sidewalls with a short (12 inch) low pressure fabric seal. Front and rear seals will be the same as those used on the rigid system. This concept affords further

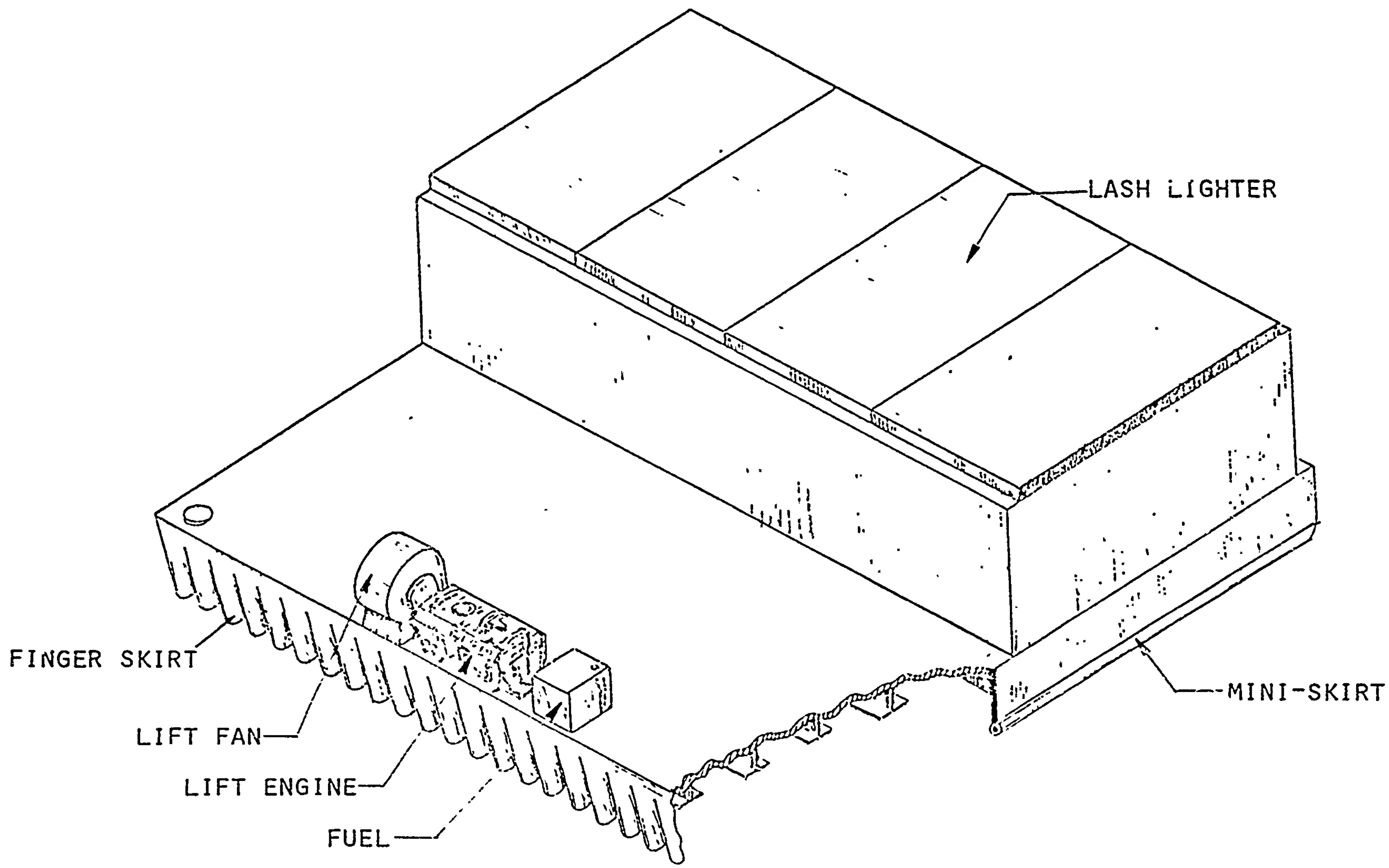


Figure 5-3. ACLV Semi-Rigid Sidewall System Concept

cost savings by eliminating almost half of the fabric parts and substituting structural steel. This will result in the exchange of fabric seal costs of up to $78,000 for the cost of increased mild steel fabrication of $3,150 to $4,727.

5.4 ACLV COST ESTIMATE

The following estimates of ACLV costs are based upon information supplied by the representative vendors contacted. Although the vendors were most helpful, a specific recommendation is neither intended or implied.

5.4.1 Packable System Cost

Component	Estimated Cost
• Trunk-Seal Assembly:	$805K
• Lift Engineering Plant: Garrett Model No. GTCP 660-4R Gas Turbine	$175 K ± 20%
• Flow Multiplier:	$ 20 K
Total	$1,000,000

5.4.2 Rigid System Cost

Component	Estimated Cost
• Seal:	$178,000.00
• Bed (mild carbon steel) Avondale Shipyard:	$ 30,150.00
• Fan Buffalo Forge Model No. L-39, Size 1085 (Galvanized):	$ 23,598.00
• Lift Engine Detroit Diesel Model 16V-149T:	$ 60,565.00
Total	$292,313.00

5.4.3 Semi-Sidewall System Cost

Component	Estimated Cost
• Seal:	$100,000.00
• Bed (mild carbon steel) Avondale Shipyard:	$ 34,877.00
• Fan Buffalo Forge Model No. L-39 Size 1085 (Galvanized):	$ 23,598.00
• Lift Engine Detroit Diesel Model 16V-149T	$ 60,565.00
Total	$219,040.00

5.4.4 Other Cost Considerations

Both the packable and rigid concepts will perform as required; therefore, basic effectiveness is considered equal, although the rigid system and its derivative are more flexible in application. When evaluating costs, system reusability must also be taken into account. Table 5-1 is a comparison of certain elements of the systems which must be considered in overall cost of ownership. Operational considerations such as handling, loading/unloading and vulnerability were not evaluated at this time.

Table 5-1. ACLV Configuration Comparison Chart

FACTOR	PACKABLE SYSTEM	RIGID SYSTEM (FABRIC SEAL)	SEMI-SIDEWALL SYSTEM
Transport Space Required	Least	Much more than packable	Most
Weight	Least	More than packable	Most
Bulk (Loaded)	Most	Least	Almost same as Fabric Seal
Number of Systems Required	One per LASH Lighter	Enough for Shuttle Flow	Enough for Shuttle Flow
Damage Resistance	Least	Highest	High
Cost (Frame-Seal)	Highest	Much Lower than Packable	Lowest
Cost (Lift Engineering)	Very High but may be reused	Much Lower than Packable	Same as Rigid System
Versatility	Lowest	Highest (overland capability)	High

Section 6

CONCLUSIONS AND RECOMMENDED SYSTEM CONFIGURATION

The results of this study incorporate an extensive literature search (see Appendix D) in an attempt to verify the findings insofar as is possible with a system which is quite radically different from what might be termed "conventional" hovercraft. Furthermore, full advantage was taken of the expertise of those individuals involved in operational and prototype ACLV and SES craft development. It is indeed fortunate to have a concentration of this resource in the immediate vicinity. The findings reported herein can, therefore, be stated with considerable confidence.

An ACLV system of the LASH lighter dimensions and weighing 500 tons is not feasible due to the high cushion pressure which was required to support the payload. This cushion pressure, while attainable of itself, gave rise to too high a wave drag to be overcome by the drawbar capability of the RH-53 helicopter. However, by reducing the maximum gross weight to 250 tons, and incorporating the skirt in a configuration which increases the cushion area, the concept of drylanding the payload up a sandy beach by helicopter tow is technically feasible. Further calculation showed that in order to dryland the cargo, the beach must be approached with some forward velocity. Cross wind will not seriously affect the operation. Whereas detailed analysis of stability was not possible, sufficient information was obtained to suggest that the craft under tow would be stable. Discussions with manufacturers of fans, gas turbine engines and diesel engines which could appropriately be used for the lift fan assembly have proven that the system is feasible from yet another aspect; namely hardware. The final area of technical feasibility is provided by the expertise of Goodyear Aerospace Corporation, who performed preliminary design on a number of skirt configurations.

The mathematical analyses conducted and reported in earlier sections apply equally well to each of the three skirt configurations considered.

Ultimate feasibility has therefore been determined from the standpoint of cost, reliability, and utility.

Based on these input parameters, it is felt that the optimum configuration is a hard deck system using the rigid sidewall with a "mini" skirt to keep the cost within the realm of a low-cost, and possibly expendable, system. The system is powered by the low cost diesel engine-driven fan in favor of the compact but prohibitively expensive gas turbine engine. The complete system recommended is shown in Figure 6-1.

Recommendations for further development include fabrication of a scale model for stability and control testing, model tests of the skirt configuration, detailed structural analysis and compatibility of the ACLV system with the LASH ship. These further developments require advances in the state-of-the-art only insofar as the stability is concerned — otherwise, all the necessary work consists of straightforward design based on sound engineering principles. It is thus feasible to dry-land a payload up a sandy beach by helicopter tow using a simple, reliable, and economical system after only moderate future development.

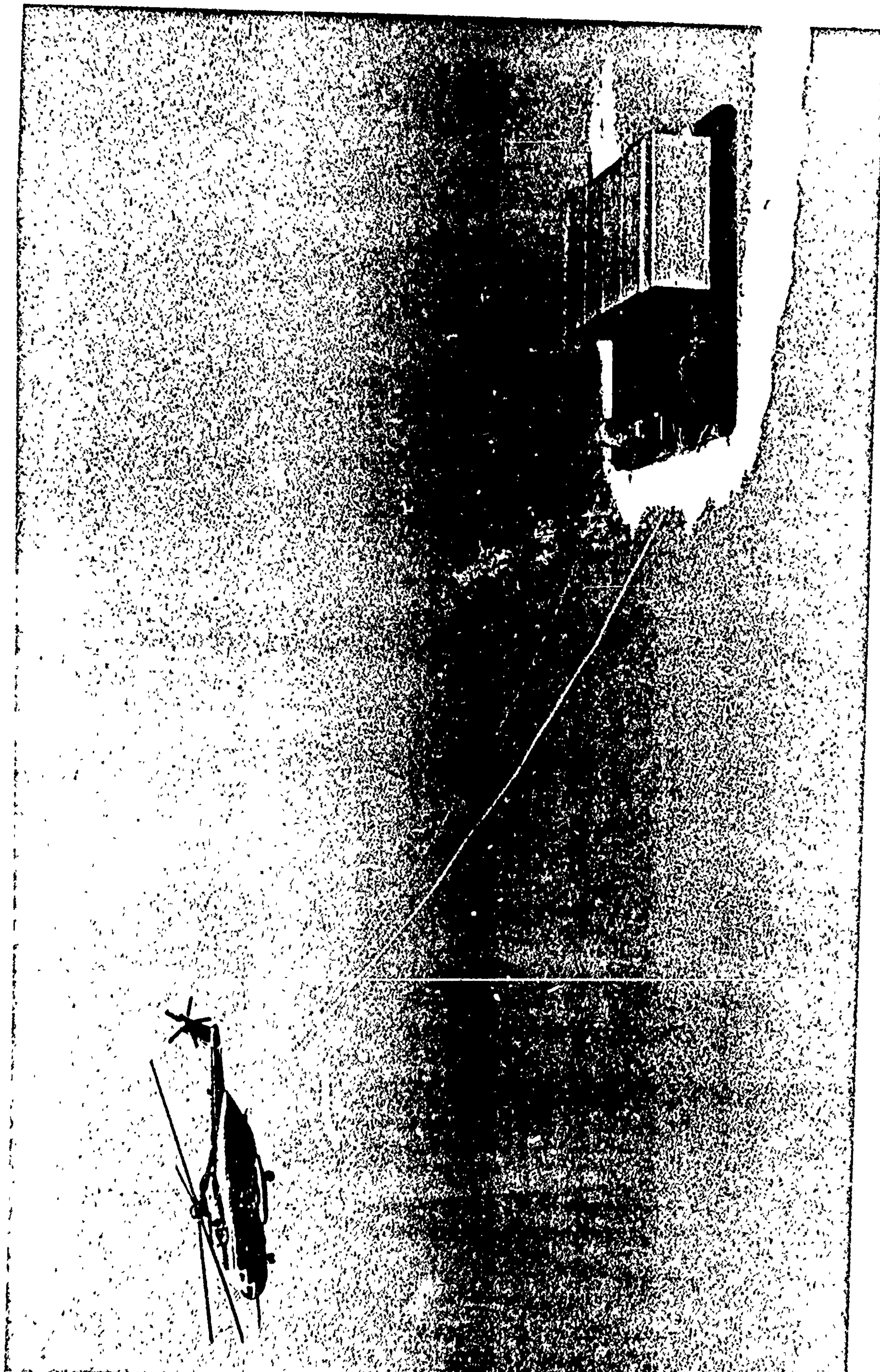


Figure 6-1. ACLV System Configuration

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Appendix A

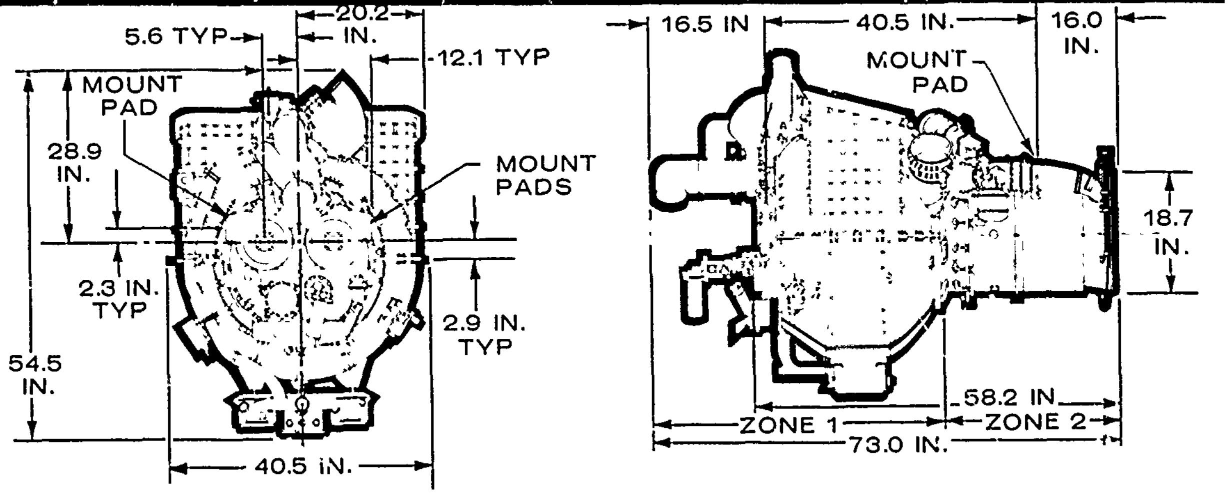
CATALOG SHEETS OF COMMERCIALLY AVAILABLE HARDWARE

R. 2

GAS TURBINE SPEC DATA

MODEL **GTCP 660-4R**

ISSUED 2/4/7



ENVELOPE DATA / Weight: (INCLUDES ACCESSORIES) 595.39 LBS(WET) Inlet Area: 474.5 SQ. IN.
Exhaust Area: 346.4 SQ. IN.

PERFORMANCE DATA AND LEADING PARTICULARS:

FUELS: MIL-T-5624 (ALL GRADES)
D1655-68 (ALL GRADES)

OILS: MIL-L-7808/23699, ESSO/ENCO TJ-15, ESSO/ENCO 5251, TEXACO/CALTEX SATO 5180, SINCLAIR TURBO OIL TYPE II, P&WA 521B

OUTPUT PAD(S): DUAL DRIVE PADS, AS 469B-A8C-2(MODIFIED) 8,000 RPM

DIRECTION OF ROTATION: CW (FACING PAD)

RATED EGT: 1215°F

ROTOR SPEED: 20,000 RPM

RATING: (FOR INDICATED APPLICATION)

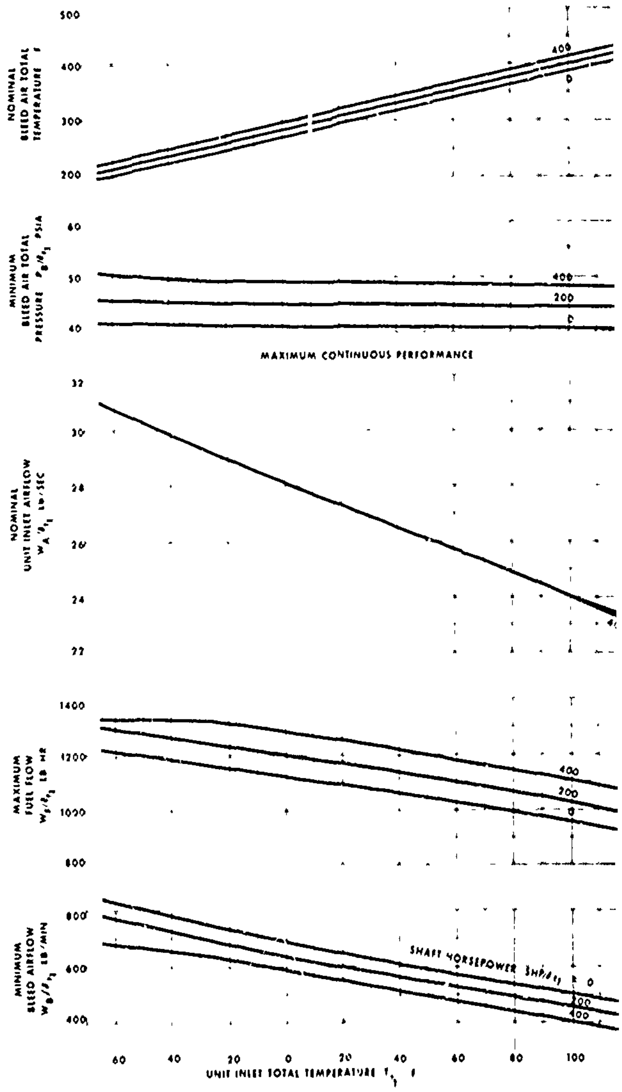
AMBIENT COND.: 100°F SEA-LEVEL DAY

BLD. AIR FLOW: 480 LB/MIN

TEMP: 440°F PRESS.: 43.8 PSIA

PRESS. RATIO: 2.980 SHAFT HP: 63

COMBINATION LOAD: SEE RATING
MAX CONTINUOUS SHAFT POWER – 300 HP



SPECIFICATION DATA:

INSTALLATION DRWG: 380716-2

MODEL SPEC.: SC-6148D

BASIC SPEC: FAA TSO C77
CATEGORY II, CLASS C

APPLICATION: BOEING 747

GTCP 660-4R

STANDARD FEATURES:

- SELF-CONTAINED LUBRICATION SYSTEM
- FUEL FILTERING
- TIME TOTALIZER
- LOW OIL PRESSURE PROTECTION
- HIGH OIL TEMPERATURE PROTECTION
- OIL QUANTITY INDICATOR SIGNAL
- SPEED INDICATOR SIGNAL
- EXHAUST GAS TEMPERATURE INDICATOR SIGNAL
- OVERSPEED PROTECTION
- EXHAUST TEMPERATURE PROTECTION
- TURBINE BLADE AND BLADE ATTACHMENT CONTAINMENT & COMPRESSOR BLADE CONTAINMENT

OPERATING ATTITUDES:

1. NORMAL - 15 DEGREES NEGATIVE DISPLACEMENT OF THE X - AXIS (EXHAUST FLANGE UP)
2. UP TO 30° DEGREES NEGATIVE DISPLACEMENT OF THE X - AXIS (EXHAUST FLANGE UP) WITH UP TO 15 DEGREES INCLINATION TO EITHER SIDE.
3. UP TO 15 DEGREES POSITIVE DISPLACEMENT OF THE X - AXIS (EXHAUST FLANGE DOWN) WITH UP TO 15 DEGREES INCLINATION TO EITHER SIDE

PREVENTION OF REVERSE WINDMILLING

STANDARD ACCESSORIES: (INCLUDED IN UNIT WEIGHT)

- OIL PUMP
- OIL FILTER
- FUEL FILTERS
- HOURMETER
- FUEL CONTROL
- OIL COOLER
- COOLING FAN
- DC STARTING MOTOR
- IGNITION SYSTEM
- SURGE CONTROL VALVE
- MAGNETIC DRAIN PLUG
- EGT THERMOCOUPLES (CHROMEL-ALUMEL)
- LOW OIL PRESSURE SWITCH
- HIGH OIL TEMPERATURE SWITCH
- TWO ELECTRONIC TURBINE CONTROLS WITH SWITCHING MODULE
- BLEED LOAD CONTROL & PRESSURE REGULATING VALVE
- INLET BLOCKAGE PROTECTION

OPTIONALS:

- START COUNTER
- FAULT INDICATION MODULE

CUSTOMER INSTALLATION CONSIDERATIONS:

FUEL REQUIREMENTS:

Pressure — 5 PSI ABOVE TRUE VAPOR PRESSURE UP TO 50 PSIG MAXIMUM

Flow — 1310 LB/HR (MAX)

ELECTRICAL REQUIREMENTS:

Starting — DC STARTER MOTOR WITH 24 VOLT POWER SOURCE
50 AMP-HR N.CAD BATTERY OR EQUIVALENT

Operation — SAME

OPERATING ENVIRONMENTS: *

Temperature — COMPRESSOR INLET: MINUS 40°F TO PLUS 130°F
LIMITS { ZONE 1 200°F; ZONE 2 450°F

Altitude — STARTING 0 TO 20,000 FT
OPERATING UNDER LOAD 0 TO 15,000 FT.

*INSTALLATION CHARACTERISTICS WILL MODIFY STATED PERFORMANCE

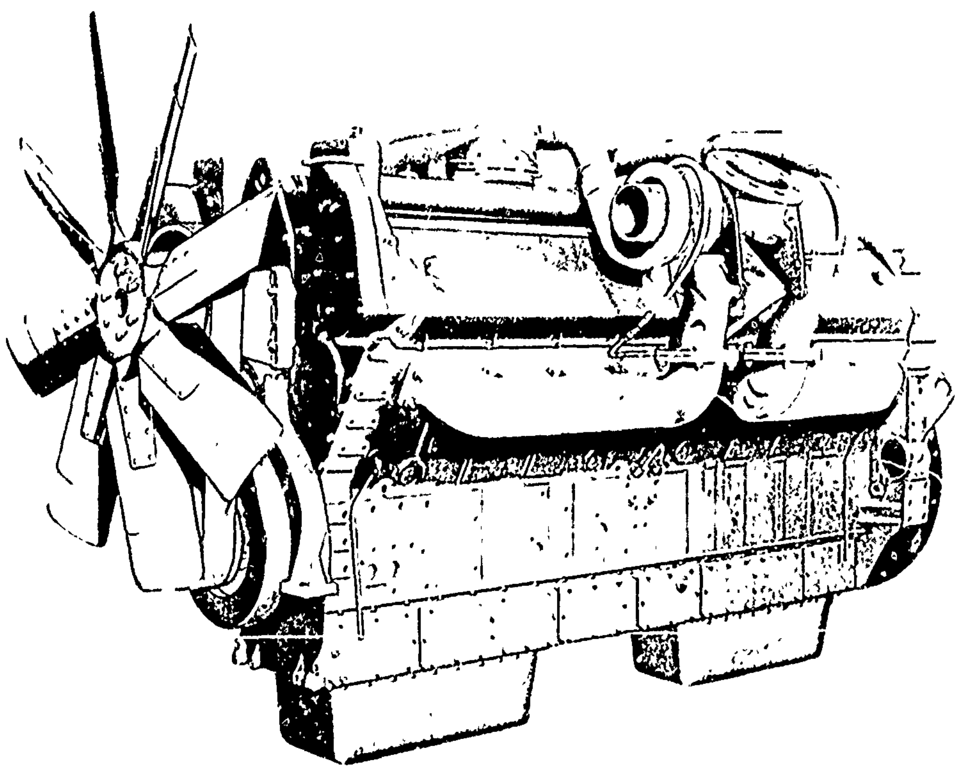
DETROIT DIESEL

FAN-TO-FLYWHEEL ENGINES

16V-149	16V-149T
1060 HP	1325 HP

MODEL

16V-149	9163-7000
16V-149T	9163-7300



Typical Model 9163-7300

DETROIT DIESEL

A Power Product of General Motors

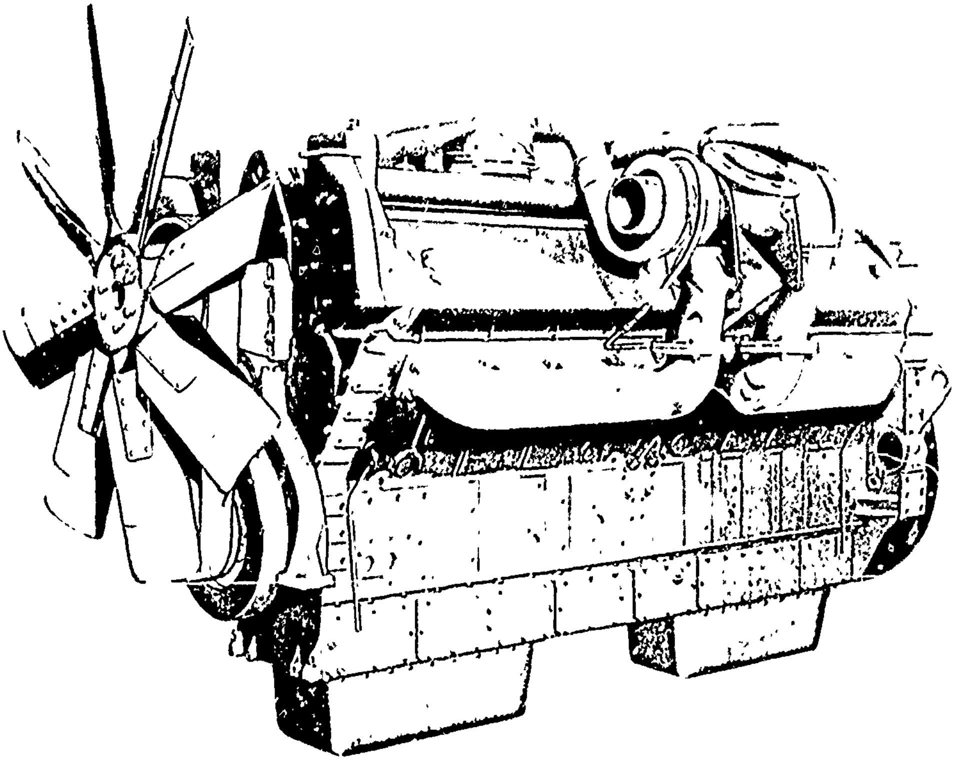
GM

MARK OF EXCELLENCE

R.5

MODEL

16V-149	9163-7000
16V-149T	9163-7300



Typical Model 9163-7300

A Power Product of General Motors

GM

MARK OF EXCELLENCE

R.5

SPECIFICATIONS

	16V-149	16V-149T
Model	9163-7000	9163-7300
Engine Type	Two Cycle	Two Cycle
No. of Cylinders	16	16
Bore and Stroke	5¾ in. x 5¾ in.	5¾ in. x 5¾ in.
Two Cycle Displacement (Every Downstroke a Power Stroke)	2384 cu. in.	2384 cu. in.
Max. Brake Horsepower —1900 RPM	1060	1325
Rated Brake Horsepower —1900 RPM	1060	1325
Continuous Brake Horsepower—1800 RPM	900	900
Torque—1500 RPM	3080 lb. ft.	
1400 RPM		3900 lb. ft.
Compression Ratio	18 to 1	18 to 1
Net Weight (Dry) with Standard Equipment (Est.)	10630	10840

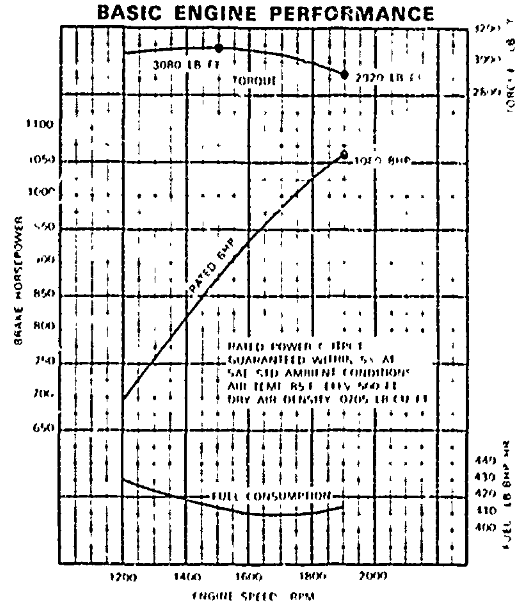
STANDARD EQUIPMENT

- Air Inlet Housing—Manual unitized shutdown
- Crankshaft Pulley
- Engine Mounts—Trunnion
- Exhaust Manifold—Center outlet
- Fan—52″—8 blade, suction, Model 9163-7000
  60″—8 blade, suction, Model 9163-7300
- Flywheel—SAE #0
- Flywheel Housing—SAE #0
- Fuel Filters and Hoses
- Generator—24 volt—30 amp A.C.
- Governor—Variable Speed
- Injectors—Cam-operated, Unit type
- Lube Oil Filters—Full-flow Filters
- Oil Cooler
- Oil Pan and Distribution System—For 15 degree inclination
- Starting Equipment—24 volt Sprag Clutch
- Throttle Controls
- Turbocharger—Model 9163-7300 only

OPTIONAL AND EXTRA EQUIPMENT AVAILABLE

PERFORMANCE

MODEL 9163-7000
WITH 130 INJECTORS
BASIC ENGINE PERFORMANCE



Rating Explanation

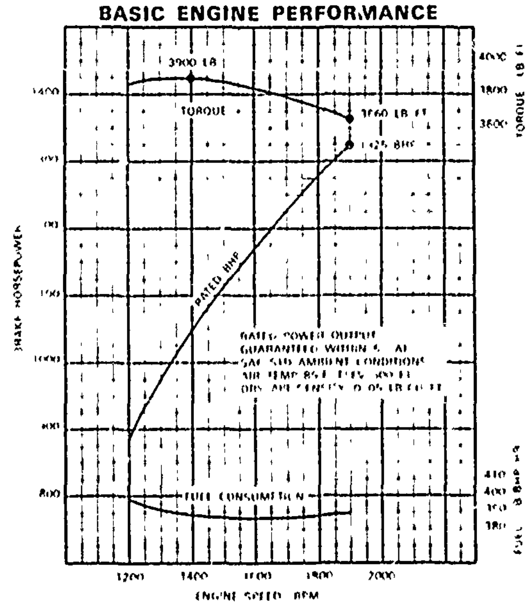
RATED BHP is the power rating for variable speed and load applica tions where full power is required intermittently Performance may be derated to improve fuel economy and extend engine life

CONTINUOUS BHP is the power rating for applications operating under a constant load and speed for long periods of time

FUEL CONSUMPTION CURVE shows fuel used in pounds per brake horsepower hour

THESE RATINGS do not include power requirements for accessory and standard equipment

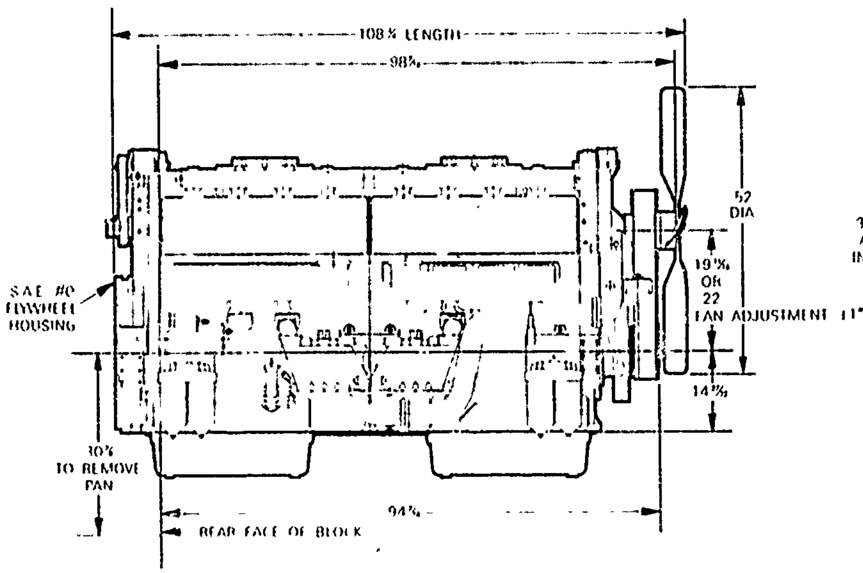
MODEL 9163-7300
WITH 150 INJECTORS
BASIC ENGINE PERFORMANCE

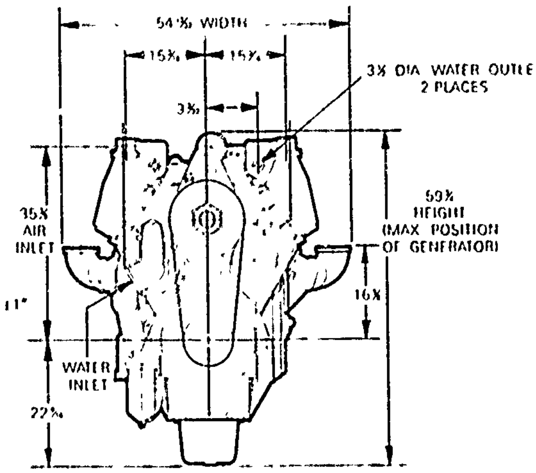


For complete engine specifications for your particular application, see your authorized Detroit Diesel representative

PRINCIPAL DIMENSIONS

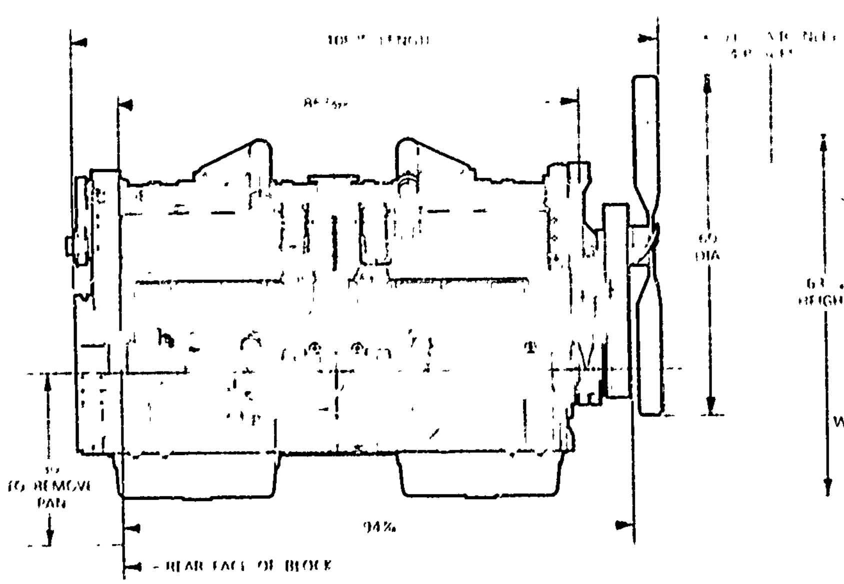
9163-7000

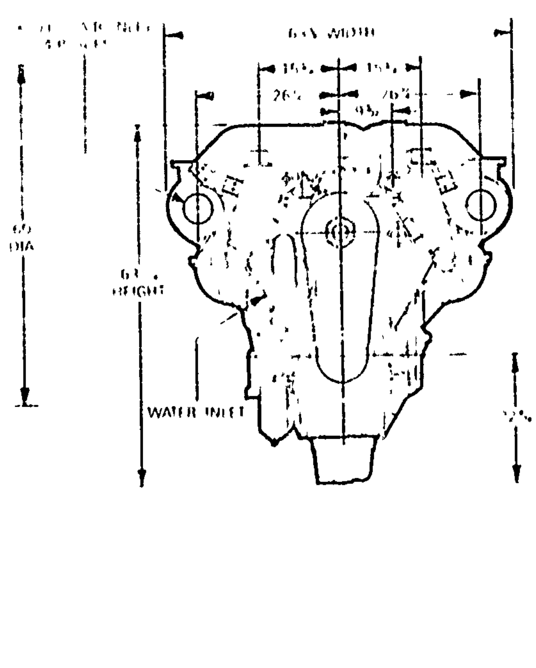




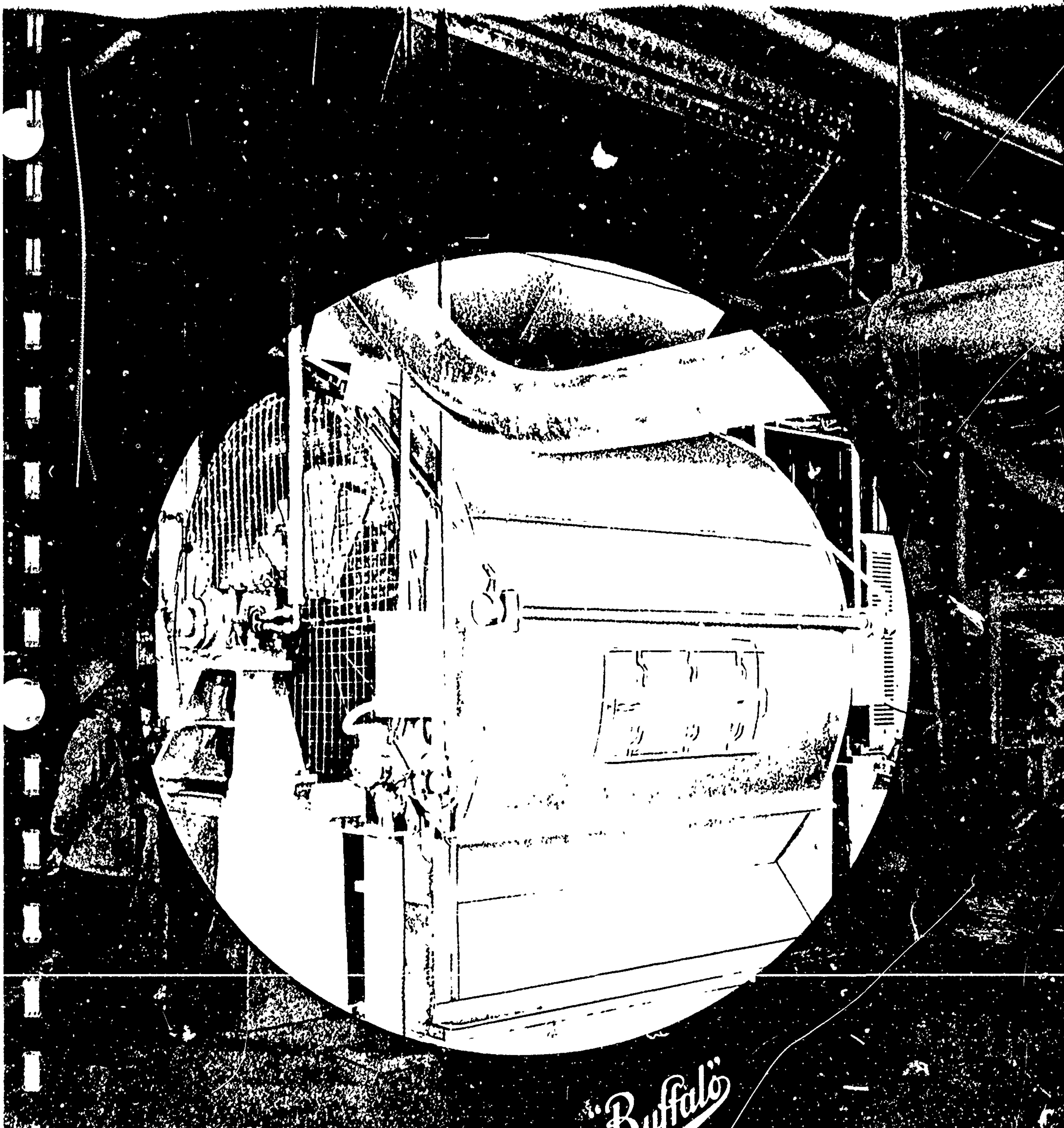
FOR COMPLETE DIMENSIONS REFER TO INSTALLATION DRAWING 25A

9163-7300





FOR COMPLETE DIMENSIONS REFER TO INSTALLATION DRAWING



"Buffalo"

HEAVY DUTY FANS

BULLETIN FD-100 / "L" SERIES

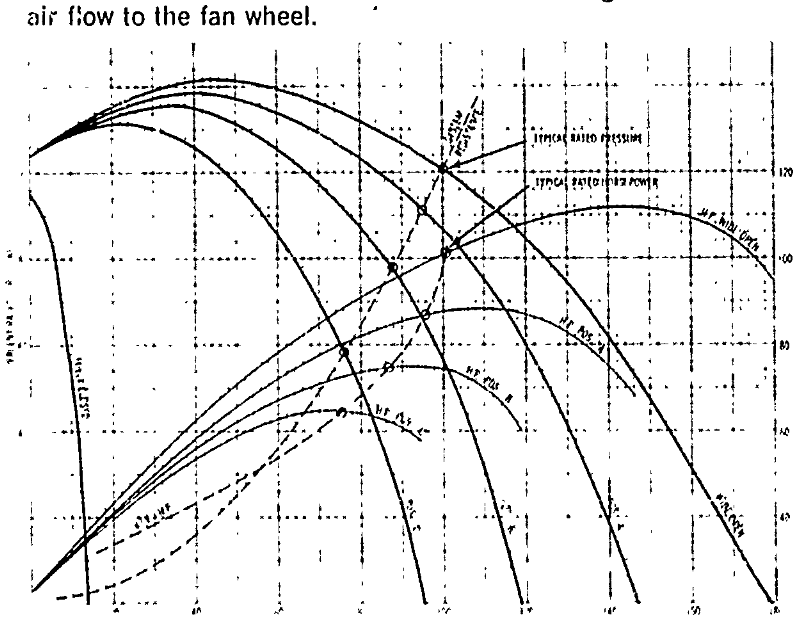
FANS/"L" SERIES

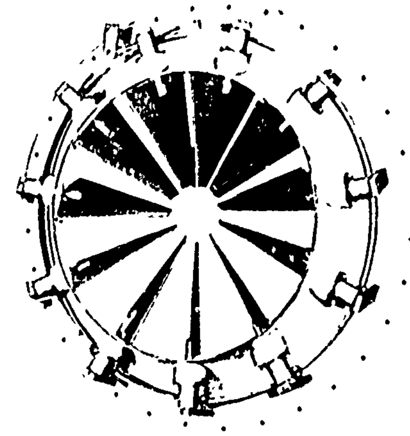
- MANUAL OR AUTOMATIC OPERATION
- REMOVABLE AS A UNIT NO BACKLASH
- NO MECHANISM IN HIGH VELOCITY AIR STREAM
- PERMANENT ALIGNMENT AND LUBRICATION

VARIABLE INLET VANES

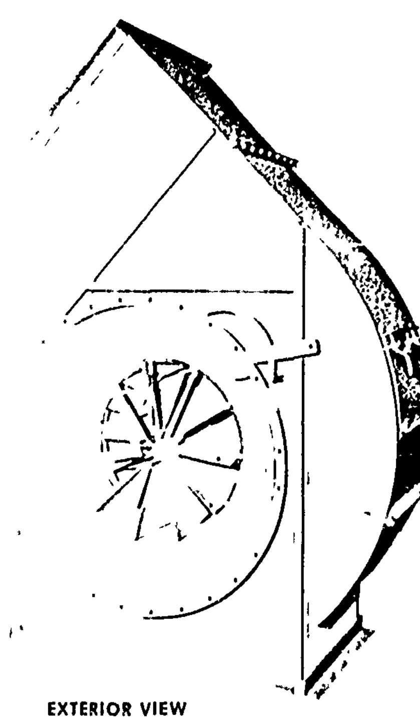
DESIGN AND CONSTRUCTION - The cantilever design variable inlet vane does not obstruct the fan inlet with gears, control levers or grease fittings. Current designs offer cleaner, dependable, trouble-free operation. As shown in the figure, each vane shaft is supported by self lubricating, sealed, anti-friction bearings completely contained in its supported housing. They are connected to a one piece control ring by crank arms. The entire assembly is perfectly aligned and has a proven record of easy operation free from backlash.

Control of fan performance, with variable inlet vanes, can be by manual adjustment or with automatic pneumatic or motor controllers. Double inlet fans have the necessary crossover mechanism for the use of one controller which gives balanced air flow to the fan wheel.





INTERIOR VIEW



EXTERIOR VIEW

PERFORMANCE - The smoothness of the L series performance curves indicates streamlined flow and no points of instability with Variable Inlet Vane control.

Any quantity of Air and Pressure under the wide open curve can be obtained by some setting of the Variable Inlet Vanes (down to about 20% of the rated capacity). The VIV, being close to the wheel, provides efficient controlled spin of the air as it enters the rotor with the resulting horsepower saving over damper control.

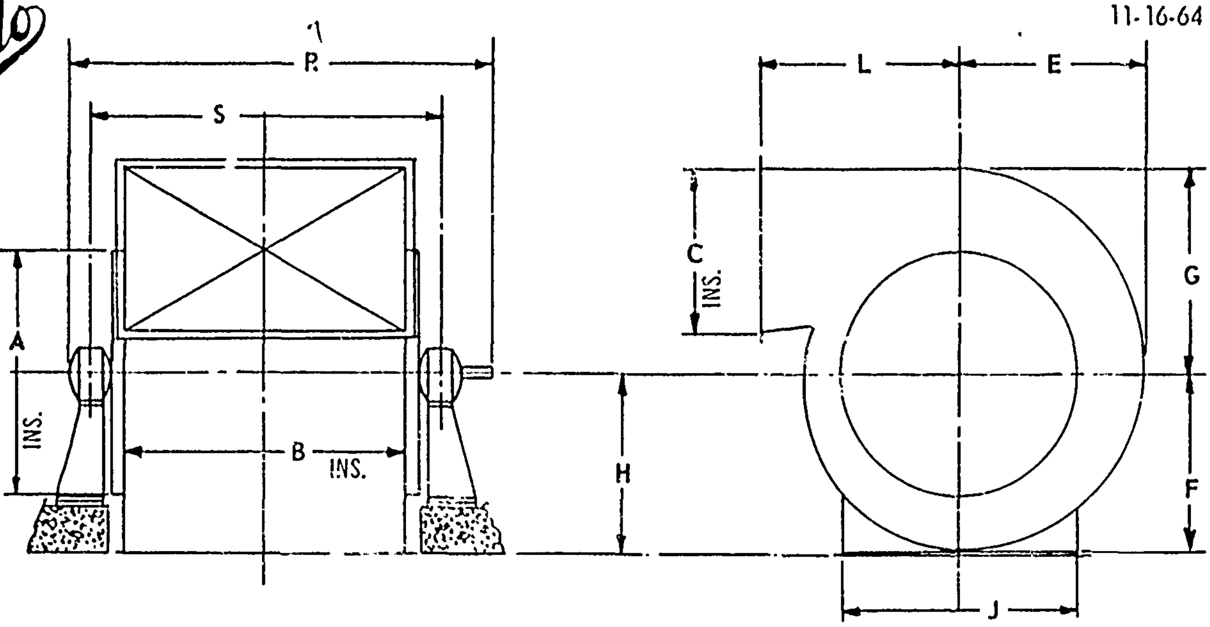
The above curve shows three positions of a VIV. The dotted line down a system resistance line and the corresponding VIV horsepower curves clearly indicate savings in horsepower.

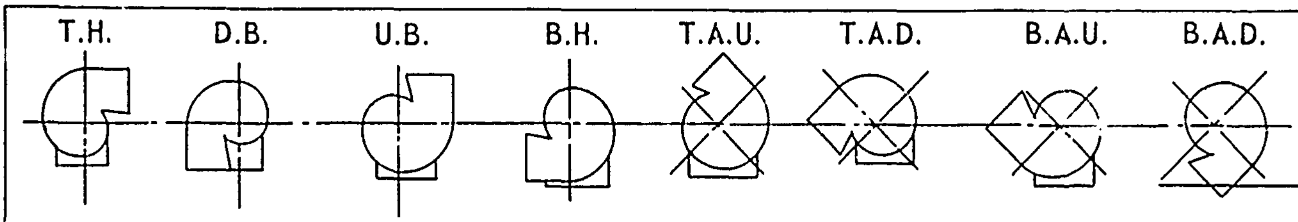
BUFFALO FORGE COMPANY / BUFFALO, NEW YORK

R. 9

"Buffalo"

FD-1003
11-16-64





TYPE L-39 D.I.D.W. ARR. 3

FAN SIZE	STD WHL. DIA.	A	B	C	E	F	G	H	J	L	R	S
600	30	$37\frac{1}{8}$	$39\frac{1}{2}$	$23\frac{7}{8}$	$28\frac{3}{4}$	$24\frac{3}{8}$	$33\frac{1}{4}$	25	39	$21\frac{1}{4}$	59	50
660	33	$40\frac{3}{4}$	$43\frac{1}{2}$	$26\frac{1}{4}$	$31\frac{1}{2}$	$26\frac{3}{4}$	$36\frac{1}{2}$	$27\frac{1}{2}$	43	23	64	55
730	$36\frac{1}{2}$	$43\frac{5}{8}$	48	29	$34\frac{3}{4}$	$29\frac{1}{2}$	$40\frac{1}{4}$	$30\frac{1}{2}$	48	$25\frac{5}{8}$	70	60
805	$40\frac{1}{4}$	$47\frac{5}{8}$	53	32	$38\frac{1}{8}$	$32\frac{1}{2}$	$44\frac{1}{8}$	$33\frac{1}{2}$	52	$27\frac{5}{8}$	77	65
890	$44\frac{1}{2}$	$53\frac{3}{8}$	$58\frac{1}{2}$	$35\frac{3}{8}$	$42\frac{1}{4}$	$35\frac{7}{8}$	49	$36\frac{1}{2}$	58	$30\frac{1}{2}$	85	72
980	49	$57\frac{3}{4}$	$64\frac{1}{2}$	39	$46\frac{3}{8}$	$39\frac{3}{8}$	$53\frac{3}{4}$	$40\frac{1}{2}$	64	$32\frac{7}{8}$	93	79
1085	$54\frac{1}{4}$	63	$71\frac{1}{2}$	$43\frac{1}{8}$	$51\frac{1}{4}$	$43\frac{1}{2}$	$59\frac{1}{2}$	$44\frac{1}{2}$	71	$36\frac{3}{8}$	101	86
1200	60	$69\frac{3}{4}$	79	$47\frac{3}{4}$	$56\frac{5}{8}$	48	$65\frac{3}{4}$	49	78	40	111	94
1320	66	$75\frac{3}{4}$	$86\frac{3}{4}$	$52\frac{1}{2}$	$62\frac{1}{4}$	$52\frac{3}{4}$	$72\frac{1}{4}$	$53\frac{1}{2}$	86	44	121	104
1460	73	$82\frac{3}{4}$	96	58	$68\frac{3}{4}$	$58\frac{1}{4}$	$79\frac{3}{4}$	59	95	$48\frac{1}{2}$	131	114
1615	$80\frac{3}{4}$	$91\frac{3}{4}$	$106\frac{1}{4}$	$64\frac{1}{8}$	76	$64\frac{1}{8}$	$88\frac{1}{8}$	$65\frac{1}{2}$	105	$53\frac{5}{8}$	141	124
1780	89	100	117	$70\frac{3}{4}$	$83\frac{3}{4}$	$70\frac{7}{8}$	$97\frac{1}{8}$	$71\frac{1}{2}$	116	59	157	137
1965	$98\frac{1}{4}$	$107\frac{1}{2}$	$129\frac{1}{4}$	$78\frac{1}{8}$	$92\frac{1}{4}$	$78\frac{1}{8}$	$107\frac{1}{8}$	79	128	$64\frac{7}{8}$	169	149

ALL DIMENSIONS ARE OUTSIDE UNLESS OTHERWISE NOTED. DIMENSIONS NOT FOR CONSTRUCTION.

Appendix B

WAVE DRAG REDUCTION OF HIGH L/B CRAFT

That which prohibits the carrying of 500 ton gross weight and limits the speed of tow at 250 tons is the wave drag. This could be significantly reduced by increasing the L/B to 4 and the hump is virtually eliminated by an increase to L/B = 6.7. This is shown in Figure B-1 (reproduced from Reference 3), which shows the wavemaking drag, R, in its conventionally normalized format. The study reported on has had as one of its objectives compatibility with the LASH ship. Consequently, high L/B could not be investigated. However, should future applications have more flexibility in configuration, higher values of L/B merit consideration.

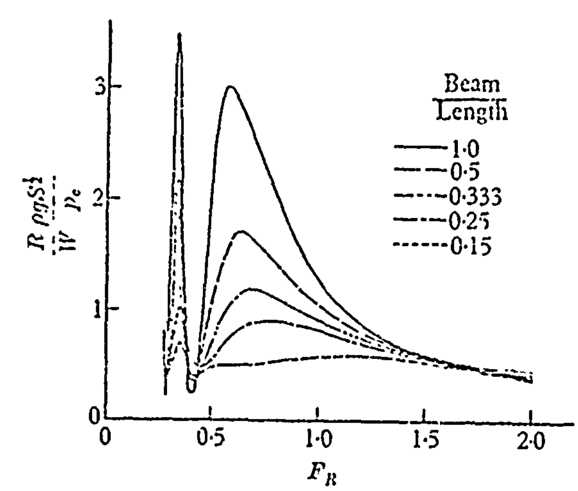


Figure B-1. Wave Drag of a Rectangular Planform Hovercraft in Deep Water.

Appendix C

LASH SYSTEM CONSIDERATIONS

The recommended configuration of the ACLV deviates considerably from the ideal L/B ratioes of 4.0 or better as described in Appendix B. With an L/B of 1.0, the ACLV will be forced to cope with wave and aerodynamic drags in excess of those normally associated with working over-water hovercraft. The reasons for this configuration constraint are strictly based upon LASH System considerations.

Since the ACLV must be carried aboard and launched from the LASH ship, its dimensions must be so adjusted. Figures C-1 and C-2 are sections of the plan and elevation views of the aft portion of the LASH ship. The overlays show the spatial relationships of the recommended ACLV configuration to the LASH System ship and lighter. The limited clearances, the crane capacity and the projected operational requirements all work together to result in the less than ideal configuration shown.

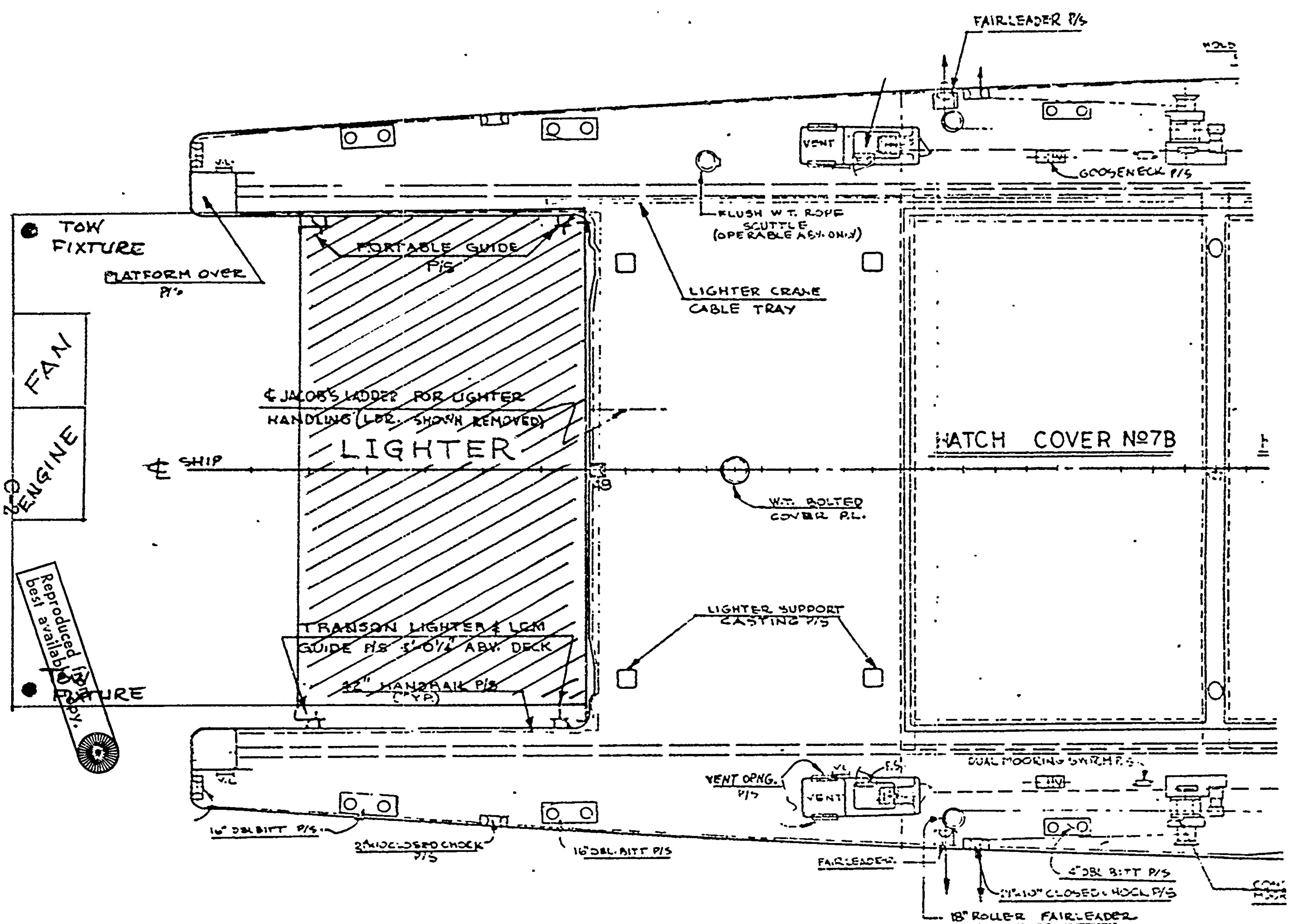


Figure C-1. LASH Ship Fantail Area Plan View

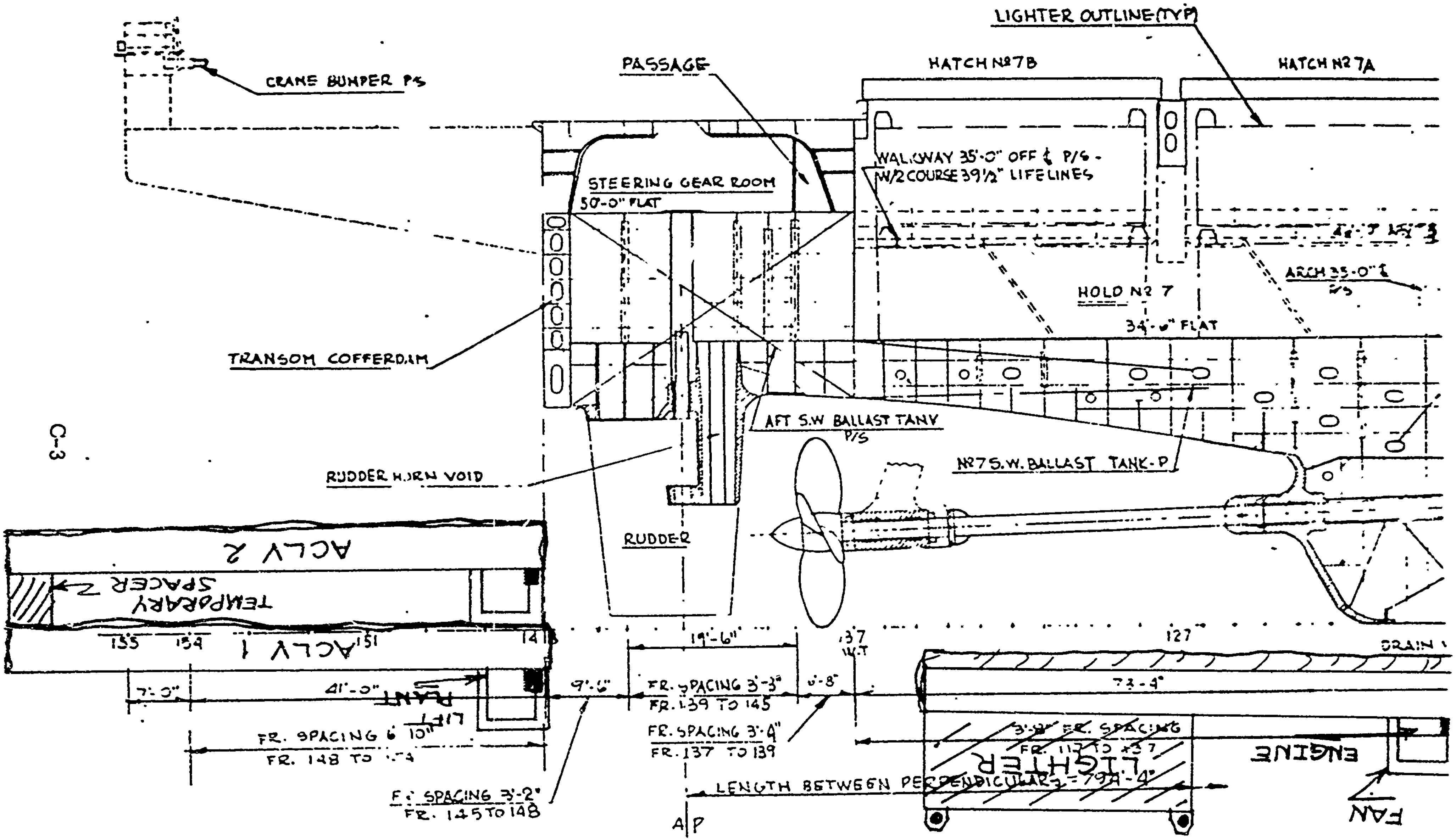


Figure C-2. LASH Ship Fantail Area Elevation View

Appendix D

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